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ABSTRACT

The integration of mathematics and science is not a new concept. However, during recent years it has been a major focus in education reform. A Wingspread conference promoted discussion regarding the integration of mathematics and science and explored ways to improve science and mathematics education in grades K-12. Papers from the conference included in this collection are: (1) "Integrating School Science and Mathematics: Fad or Folly?" (Lynn A. Steen), is organized around three basic issues: philosophy, coherence, and instruction; (2) "Mathematics and Science Education: Convergence or Divergence" (John A. Dossey), discusses three reasons why mathematics education has moved away from "direct ties" with science education in the last century; (3) "Breaking What Barriers between Science and Mathematics? Six Myths from a Technological Perspective" (Carl F. Berger), approaches the integration of science and mathematics education from a technological perspective; (4) "Video Environments for Connecting Mathematics, Science, and Other Disciplines" (John D. Bransford and The Cognition and Technology Group at Vanderbilt), argues that the integration of science and mathematics instruction is highly desirable not as an end in itself but as a means to achieve other goals; and (5) "Integrating Mathematics and Science" (Robert F. Tinker), reflects on the logic of integrating mathematics and science tempered by the reality of practice at all grade levels. One third of the document is composed of the appendices. Appendices include: author biographies; a list of the Wingspread Conference Program and participants; and a report from the conference entitled "A Network for Integrated Science and Mathematics Teaching and Learning" (Donna Berlin and Arthur White). (ZWH)

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School Science and Mathematics Association
Topics for Teachers Series Number 7

NSF/SSMA V.ingspread Conference:
A Network for Integrated Science and Mathematics
Teaching and Learning

CONFERENCE PLENARY PAPERS

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Donna F. Berlin

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Introduction

In 1990, the National Governor's Association chaired by Bill Clinton (then Governor of Arkansas) in a rare collaboration with the President of the United States, George Bush, set forth a set of National Goals for Education. Among these goals is the assertion that U.S. students will be first in the world in science and mathematics achievement by the year 2000. Science and mathematics are critical areas in the education of all students. Future citizenry must be both scientifically and mathematically literate and possess the technological expertise to function in this information era and compete in the "New World Order" marketplace. In this atmosphere of educational advancement/reform, the integration of science and mathematics is suggested as a promising path to improve both science and mathematics teaching and learning.

An Idea Whose Time Has Come

The integration of science and mathematics in schools is a popular, but not novel concept. Witness the attention given to this topic at recent conferences of science and mathematics teachers and in recent science and mathematics reform documents. Yet this concept is not new at all. Since the turn of the century, one professional organization, the School Science and Mathematics Association (formerly the Central Association of Science and Mathematics Teachers), has published numerous articles on this topic. The National Science Foundation has funded numerous curriculum projects and has sponsored two national level conferences focused upon science and mathematics integration, one in 1967 and another in 1991 (related to this publication).

> The alliance between science and mathematics has a long history, dating back centuries. Science provides mathematics with interesting problems to investigate, and mathematics provides science with powerful tools to use in analyzing data.... Science and mathematics are both trying to discover general patterns and relationships, and in this sense they are part of the same endeavor (Rutherford & Ahlgren, 1990).

> Since mathematics is both the language of science and a science of patterns, the special links between mathematics and science are far more than just those between theory and applications. The methodology of mathematical inquiry shares with the scientific method a focus on exploration, investigation, conjecture,

evidence, and reasoning. Firmer school ties between science and mathematics should especially help students' grasp of both fields (National Research Council, 1990).

Since the early part of the century, writers have approached the subject of integrating science and mathematics in the schools, but in a recent survey of the research Berlin (1991) found that only 7% could be classified as research. Deeper inspection reveals that this research is inconsistent, not comparable, and does not provide a research base from which to make integration decisions.

Definitional Problems

To compound the problem, the definition of integration is not consistent. For some, integration means teaching the prerequisite mathematics skills prior to the science concepts (an application approach). For others, it is a concurrent teaching of the two disciplines (a conceptual approach). There is critical need for additional research and clarification in the area of integrated science and mathematics teaching and learning. Integration across content, with a primary focus on the integration of science and mathematics education, is part of the research agenda of The National Center for Research in Science Teaching and Learning, The Ohio State University, Columbus, Ohio.

The Wingspread Conference

In April, 1991 a conference entitled "A Network for Integrated Science and Mathematics Teaching and Learning" was convened at The Johnson Foundation Wingspread facility, Racine, Wisconsin. It was sponsored by the National Science Foundation, School Science and Mathematics Association, and The Johnson Foundation. Attendees were educators, professional association leaders, curriculum developers, and members of the scientific community. This diverse group gathered for three days to explore ways to improve science and mathematics education in elementary, middle/junior, and high schools across the country through the integration of these two disciplines.

At the opening session, Dr. Donna F. Berlin of The Ohio State University presented an overview of the literature on the integration of science and mathematics education. (A bibliography on this topic was cooperatively published by The National Center for Science Teaching and Learning, School Science and Mathematics Association, and the ERIC Clearinghouse for Science, Mathematics, and Environmental Education.) Her overview of the theoretical, research, curriculum, and instructional literature in the field of integrated science and mathematics education revealed that of the 423 citations, approximately 326 were essentially science instructional activities that included mathematics-related concepts. This type of integration is a product of the nature of the activity rather than of conscious design, and involves isolated activities rather than organized programs. Berlin's review highlighted a profound lack of research documents. Out of 99 citations related to theory and research, only 22 concerned research. Further, inconsistent definitions of integration precluded valid comparisons within the research literature. There is clearly a need for careful conceptualization and additional research on integrated science and mathematics teaching and learning.

In an effort to address the lack of clear conceptualization in the area of integrated science and mathematics education, a discussion/working group format was used at the Wingspread Conference focusing on the following topics:

Define integration and develop a rationale for integrated science and mathematics teaching and learning.

List guidelines for the infusion of integrated science and mathematics teaching and learning into school practice.

Identify a list of high priority research questions related to integrated science and mathematics teaching and learning.

Plenary Papers

In preparation for this conference, five plenary papers were commissioned to provide a spectrum of perspectives and set the stage for exploration through dialogue and discussion among the participants. Authors include Carl F. Berger (University of Michigan, Ann Arbor, MI), John D. Bransford (Vanderbilt University, Nashville, TN), John A. Dossey (Illinois State University, Normal, IL), Lynn A. Steen (St. Olaf College, Northfield, MN), and Robert F. Tinker (TERC, Cambridge, MA).

This document is a compilation of the plenary papers from the NSF/SSMA Wingspread Conference entitled "A Network for Integrated Science and Mathematics Teaching and Learning." The papers are reproduced in the order in which they were presented at the conference.

In the first paper, Steen organizes his "analysis of integration" around three basic issues: philosophy, coherence, and instruction. In his discussion of the first issue, five scenarios for the integration of mathematics and science education along with their potential benefits and detriments are presented. They include: 1) employing mathematical methods thoroughly in science instruction and coordinating both curricula, 2) employing scientific examples and methods thoroughly in mathematics instruction and coordinating both curricula, 3) teaching mathematics entirely as part of science -- as its language and tool, 4) teaching science entirely as part of mathematics -- as its principle application, and 5) employing mathematical methods in science and scientific methods thoroughly in mathematics and coordinating both curricula. It is the fifth scenario that is most appealing to Steen. He provides numerous examples of appropriate ways in which to cross-fertilize the instructional methods of mathematics and science. In his "coherence" section, Steen discusses three hurdles to the integration of science and mathematics education. They are: 1) planning appropriate coordination in terms of topic sequence and providing connections, 2) implementing coordination when student electives are involved, and 3) coordination within science itself. In the final section, instruction, Steen presents three additional problems for consideration: 1) science teachers are not prepared to teach all of science in an integrated fashion; 2) most science teachers, with the exception of those in physics and chemistry, are not adequately prepared in quantitative methods in order to integrate mathematics and science and teach advanced mathematics; and 3) few mathematics teachers are prepared to teach even one of the sciences. Despite the litany of barriers to the integration of science and mathematics education, Steen concludes that integration based upon the blending of instructional methods (i.e., focusing upon "how you teach, before worrying about what you teach") in the hands of elementary school mathematics-science specialist teachers is viable and possible.

In the second paper, Dossey discusses three reasons why mathematics education has moved away from "direct ties" (i.e., divergence) with science education in the last century. They include the promotion of links between mathematics education and other disciplines such as those in the social sciences and business, the rapid growth and expansion of mathematics as a discipline, and the lack of consensus among science educators as to what should be taught and at what grade levels. Dossey then discusses and provides examples of a variety of curricular models that have been considered as integrated: the simultaneous, braided, topical, unified, and interdisciplinary models. Using these integration models as a framework, Dossey traces the historical development of integrated mathematics curricula. Reflecting upon the differences in the mathematics and science curriculum, particularly in the rate of reform, provides the backdrop for his discussion of the integration of science and mathematics education. For Dossey, the NCTM Curriculum and Evaluation Standards for School Mathematics (1989) serves as the "key to integration" (i.e., convergence). The basic process standards as well as some specific content standards are cited as areas in which some instructional time could be used to connect mathematics and science and effectively teach both disciplines in an interdisciplinary manner. Dossey concludes his paper with a discussion of the need to address significant challenges to the integration of mathematics and science education. They include the development of supporting curricular materials; methods to accurately assess student progress; changes in preservice and inservice teacher education; and a strong public relations program to gain the support and commitment of the educational and scientific communities, students, and the public at large. Of particular significance is the need for research related to integrated science and mathematics teaching and learning.

Berger, in the third paper, approaches the integration of science and mathematics education from a technological perspective. He proposes six myths that support "The Great Myth", that is, "there is a barrier between science and mathematics." For each myth, Berger provides examples of how technology can "blast through the barrier between science and mathematics." "Myth one: The myth of analysis before synthesis." For example, to understand physics, traditionally it was believed that students must first have an analytic understanding of differentiation and integration. However, evidence from research using technology has indicated that students can attain a conceptual understanding of differentiation through hands-on experiences using technology before exposure to analytic procedures. "Myth two: The myth of the word problem." To dispel this myth, Berger cites the *Jasper Woodbury* series as a way for students to apply their knowledge on real world problems that integrate science and mathematics using an embedded, video format. "Myth three: The myth of science as reality, math as numbers and formulas." *SuperQuest* is cited as a computer program which enables students to explore "computational science," a novel approach to the integration of science and mathematics. "Myth four: The six simple machines or taking square roots." Berger discusses this myth in terms of the need to re-examine the science and mathematics curricula in order to benefit from the integration of these disciplines and the use of modern technology. "Myth 5: If it moves have the students graph it." Graphing programs or video-computer integrated packages like *TapeMeasure* are suggested to enable students to achieve significant conceptual learning that does not often emerge from the hand construction of graphs. "Myth 6: The myth of the ordered pair." In a five year research project, Berger and his associates investigated the potential of computerized data gathering and analysis in teaching graphics in both math and science. Results indicate that student problem solving ability was enhanced by the use of the graphics program. Once again, integration is being advanced through the use of technology. In conclusion, Berger revisits "The Great Myth Again: There is a barrier between science and mathematics." It is his belief that technology is a powerful tool that needs to be explored in terms of "what we teach, how we teach and what's important to teach" in order to break down the barriers between science and mathematics.

In the fourth paper, John Bransford argues that the integration of science and mathematics instruction is "highly desirable not as an end in itself but as a means to achieve other goals. The goals that we want to achieve are to help students experience the excitement and importance of mathematical and scientific inquiry, to realize that it is within their potential to engage in such inquiry, and to offer them the kinds of experiences that will set the stage for lifelong learning." Several reasons are cited for encouraging the integration of mathematics and science instruction. These include: 1) optimizing instructional time across the subject areas; 2) making knowledge less inert through experiences that help students to understand the value of knowledge, make connections with other aspects of their knowledge, and provide authentic and multiple perspectives; and 3) using mathematics, enhanced by the use of technology-based tools, to quantify information and develop models to explain phenomena. The burden placed on both math and science teachers in terms of the time and effort to develop the needed content knowledge (both conceptual and procedural) and pedagogical skills to integrate math and science instruction is discussed as a major barrier to knowledge integration. To overcome this barrier, Bransford promotes the concept of "anchored instruction as an approach to integrative collaborative inquiry." The remainder of Bransford's paper provides a theoretical rationale, design principles, and a detailed description of the *Jasper Woodbury Problem Solving Series* (specifically, *Rescue at Boone's Meadow*). This series provides a videodisc-based, adventure environment along with analogs and extensions to motivate students and provide a realistic context for inquiry, problem solving, and reasoning. Math, science, geography, history, and literature are integrated in this format. The *Scientists-in-Action Series*, multimedia publishing software, tools for modeling, and teleconferencing are other ways to integrate math and science instruction by providing a common ground for exploration, collaboration, and learning for both students and teachers.

Finally, Robert Tinker reflects on the logic of integrating mathematics and science tempered by the reality of practice at all grade levels - elementary, middle school, high school, and college. Integration is impeded by the traditional elementary school mathematics and science curriculum and the specialization of faculty and courses at the high school and college levels. It is his belief that "the desire to integrate the two disciplines must come from, and be part of, a desire to re-fashion mathematics and science instruction...." Instead of "teaching students," the goal is to "empower students to undertake original investigations, to do mathematics and science." Integral to this approach is a commitment to student project activities, a curriculum that supports a project-oriented learning environment, and alternative assessment. Tinker reviews the historical support for student project activities. The use of projects provides a real context relevant to student needs and interests which is motivating and facilitates learning. The use of technology to support a project-oriented environment including telecommunications, microcomputer-based labs, and analytical tools is seen as a particularly attractive enhancement to this approach. The integration of mathematics and science develops naturally as a consequence of the changes in the learning environment (e.g., project-orientation, teacher preparation, scheduling). Tinker concludes with a description of some of the work being conducted at TERC (e.g., *Used Numbers, Network Science*) that focuses upon innovative student project activities, supportive curricula, and alternative assessments.

An Invitation

The five plenary papers here provide several interesting perspectives on the integration of science and mathematics teaching and learning. They set the stage for building a research agenda and deliberations about curriculum infusion. Though specifically prepared to serve as a springboard for discussion at the April, 1991 Wingspread Conference, we invite you to use these papers to engage your colleagues and students in the difficult process of constructing a vision for integrated science and mathematics teaching and learning.

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Integrating School Science and Mathematics: Fad or Folly?

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Talk of integration is, for most educated liberals, a rhetorical engine that can be coupled to any trainload of goods that needs to be pulled over the mountain pass of public opinion. Surely no one can object to the ideal of integration. The alternative--disintegration, segregation, isolation--leaves good intellectual produce stranded on a siding with no hope of forward motion.

The goal in education is to get our train -- our students -- over the mountain pass. In our haste to reach the summit, we should not ignore the key question of strategy: can we climb the long grade better with one giant train led by the powerful engine of integration or with several smaller trains progressing along different tracks and at different speeds?

A strategic analysis of "integration" requires what economists call "disaggregation." We begin by examining three basic issues -- philosophy, coherence, and instruction -- and then conclude with some cautious recommendations.

Philosophy

The language of the conference theme sounds symmetrical, as if the changes in science education required to achieve curricular integration will be comparable to the changes in mathematics education required for the same objective. But since the relationship between science and mathematics is not itself symmetrical -- mathematics is the language of science, not the other way around -- it is not at all clear whether the goal of integration is best described by a word with symmetrical connotations.

It is easy to imagine several possibilities for how the proposed change might come about:

- By employing mathematical methods thoroughly in science instruction and taking the necessary steps to coordinate the curricula of the two subjects. This would have great benefits both for mathematics and for science. For mathematics, it would ensure that students see the mathematics they study actually being used, and it would reinforce their learning. For science, it would help advance instruction from the present descriptive (almost pre-scientific) stage to a form that provides an honest introduction to modern scientific method. Adding modest amounts of mathematics will help make school science scientific.

- By employing scientific examples and methods thoroughly in mathematics instruction, and taking the necessary steps to coordinate the curricula of the two subjects. This too would have great benefit both for mathematics and for science, but in uncommon ways. For mathematics, it would reinforce the perspective of investigation, exploration, and experimentation that is so important to all contemporary curricular recommendations. For science, it would help underscore the importance of careful data analysis, logical thinking, and modelling as part of the scientific method.

- By teaching mathematics entirely as part of science -- as its language and ubiquitous tool -- in order to better motivate and reinforce the study of mathematics while at the same time strengthening the quantitative component of science instruction. I suspect that this would be a disaster both for science and for mathematics. Few teachers are equipped to give both subjects the emphasis they deserve. Mathematics teachers are likely to slight (and distort) science in their haste to cover traditional mathematics uncontaminated with the vagaries of real data; science teachers are likely to select only a part of mathematics that is necessary and useful for the science they are teaching, leaving untaught vast parts of the subject that are necessary for later work but not directly applicable to school science.

- By teaching science entirely as part of mathematics -- as its principle application. This too, I fear, would produce a disaster for the same reason: no teachers are prepared to do equal justice to both subjects. (I must add that there are more likely to be positive exceptions in elementary school than in middle school or high school, since at the elementary level the same teacher normally teaches both subjects. Of course, relatively few elementary teachers are really well prepared in either science or mathematics. The limited number who are capable of delivering a properly integrated curriculum would not make a significant dent in the problems of U.S. education.)

- By employing mathematical methods thoroughly in science, and scientific methods thoroughly in mathematics, coordinating both subjects sufficiently to make this feasible. This is, I submit, an ideal situation. Each discipline, science and mathematics, would accrue benefits from an infusion of methods of the other, but neither would lose its identity or distinguishing features in an artificial effort at union. There are, after all, important differences between science and mathematics, both philosophical, methodological, and historical. These should not be lost in a misguided effort at homogenization.

To make this discussion more concrete, it may help to give a few suggestions of specific ways in which constructive cross-fertilization of methods and topics might come about.

Students gathering data in a science or social studies course can be asked to use elementary tools of data analysis to organize these data and to formulate conjectures for further testing. By using real data, students will encounter all the anomalies of authentic problems -- inconsistencies, outliers, errors. Children can, of course practice arithmetic on any data they gather. Examples of ratios and proportional reasoning abound in science, providing extensive experience in a very important topic that students often do not master. Older students can gain good experience in routine mathematical tools of graphing, calculation, and simple algebra (in curve fitting). Beginning algebra students can fit lines by eye, then figure out their equations. More advanced students can investigate transformations to linearize non-linear data.

In a similar fashion, students studying mathematics can be asked to apply what they learn to situations in the world around them. Children can be introduced to scientific strategies of observation, recording, and calculation with numeric data such as records of rainfall or temperature. Collections of leaves can be used to develop non-numeric habits of classification and pattern-recognition. Geometry students can be asked to lay out the foundations of a building with string and stakes, and discover just how important the word "plane" is in plane geometry -- and how difficult it is to achieve in the real three dimensional world. Algebra students can be asked to gather data and make conjectures about patterns in algebraic structures, and then try to prove them.

Clearly there are many possibilities of such integrating activities. My point in citing these examples is not to catalogue what might be done, but to illustrate a very important difference in perspective. In teaching science, one would want to employ whichever mathematical techniques are suitable to the task, whereas in teaching mathematics one would seek whichever science domains help illustrate and apply the mathematics. These differences in perspective are part of the instinct of the professionals who teach science and mathematics, and they are, for the most part, entirely justifiable.

These differences are essential to proper understanding of a fundamental difference between mathematics and science:

- **Science seeks to understand nature.**

- **Mathematics reveals order and pattern.**

The subject of science is nature; the subject of mathematics is pattern. Each can contribute to the other, but they are fundamentally different enterprises.

So too are the crafts of mathematics education and science education. Good mathematics teachers develop various strategies to help students construct for themselves the mental structures of mathematics that will become a unique part of their own working intelligence. Similarly, science teachers lead students to develop the habits and instincts of a working scientist, to make the scientific method part of their own repertoire of approaches to the world.

Effective education, therefore, must not only teach students about science and mathematics, but teach them in what respects they are similar and in what respects they are different. There is no intrinsic value to an educational program of integration whose primary purpose (or effect) is to diminish student understanding of essential differences.

Coherence

I come now to my second key issue: how could one coordinate mathematics and science in a coherent curriculum. Regardless of which model for integration one selects, careful coordination will be required. Again, I foresee several hurdles, most of which unfortunately appear to be insurmountable:

- Planning appropriate coordination of mathematics and science. Effective instruction will depend on a curriculum that introduces important topics in both science and mathematics in a suitable order with appropriate linkages between them. This will not be too difficult in the elementary grades, but as the mathematics and science curricula proliferate and diversify in the middle and upper grades, it will be increasingly difficult to develop a workable model even on paper, much less in the classroom.

- Implementing coordination whenever student electives begin to affect curricular choices. Coherence in this context seems to be impossible. Each chemistry class, for instance, will have students whose mathematical preparation spreads out over three or four years of high school mathematics. Similarly, advanced mathematics classes will have many students who do not elect to take advanced science courses. In such a context, the liabilities of an integrated curriculum quickly overwhelm the advantages.

- Coordination within science itself. Science is not really homogeneous; there are many sciences with different traditions and methodologies. Coordination among these sciences will be at least as difficult, if not more so, than coordination between science and mathematics. While it may be possible, albeit difficult, for some scientists and teachers to agree on a coordinated multidisciplinary pattern for biology, chemistry, earth science, and physics, such a plan will do little good so long as other scientists and teachers argue vigorously for interdisciplinary science following themes such as environment, health, and energy. Surely there is little prospect of thorough integration with mathematics if the science curriculum itself is up for grabs. The NCTM Standards provide a contemporary fixed point in curriculum planning for mathematics. Where is there a comparable document for science that enjoys as widespread support?

Instruction

Finally, to the crux of the matter: teaching and learning. Is it possible -- in this real world, not some Platonic universe -- to teach an entire curriculum that integrates science and mathematics? The answer, I believe, is very simple: No. Indeed, since we cannot seem to teach either discipline separately very well, why should we think we could succeed with the vastly more difficult task of an integrated curriculum?

Sciences teachers do not have sufficient breadth across the sciences to teach all of science in an integrated fashion. Very few school science teachers, for example, are sufficiently comfortable with physics to introduce students in a suitable fashion to fundamental physical concepts such as mass, force, momentum, and energy, much less to angular momentum or action at a distance. Teachers who teach out of their zone of comfort too often teach only vocabulary and terms, since that is all they really know.

Except for those prepared in chemistry and physics, most science teachers do not have sufficient preparation in quantitative methods to successfully integrate mathematics and science, much less to teach mathematics beyond the level of the middle school curriculum. Teaching high school mathematics really does require as preparation a full undergraduate major in mathematics. Current science teachers do not have this background, and prospective science teachers could not be expected to acquire it unless they undertook a six year program of teacher preparation.

Finally, to complete my litany of liabilities, few mathematics teachers are as well prepared in even one science; practically none are competent in all. What's worse, the predominant emphasis of school science has strongest links to the biological and life sciences, which is the area in which mathematics majors are typically least prepared. Moreover, unless mathematics teachers have studied a lot of science, they are not likely to understand or empathize sufficiently with the observation-rich, hands-on, laboratory-intensive aspects of the scientific method.

Silver Linings

I don't enjoy carrying out such a negative analysis, and rather hope that perhaps others will be able to prove me wrong. Nevertheless, I don't see any escape from the general conclusion that any broad-brush attempt to integrate curriculum and courses in science and mathematics is doomed to failure.

There are, however, some silver linings in the thundercloud. Elementary school is an obvious exception to many of my concerns about philosophy, coherence, and instruction. I believe it should be possible to develop a good coherent joint curriculum in science and mathematics in the first 4-6 grades, doing justice to both fields while also laying sound foundations for future study. The major impediment would concern the number of teachers who are capable of teaching such a curriculum. It is clearly small. But it is also possible, and important for the nation, to educate a cadre of elementary school mathematics-science specialist teachers who would be both enthusiastic about science and also capable of teaching a coordinated curriculum.

My second silver lining is actually the beginning of a sunburst: instead of worrying about integrating content, let's think instead about integrating instructional methodologies.

Exploratory, investigative, discovery learning that is typical of the best science instruction is one of the features of the new NCTM standards. Children learn by doing, their actions helping construct their personal knowledge. Involvement in learning increases, as does long-term retention. Active, exploratory learning works as well in mathematics as it does in science.

Similarly, the compelling logic of inference and deduction can help the students experience the special power of science. Absent the rigorous logic of inference that is typical of mathematics, science instruction can easily degenerate into description, demonstration, and memorization. Without the intrinsic authority of inference, the authority found in science becomes extrinsic, hence heretical: students believe what teachers tell them, not what they have logically demonstrated from evidence. If the methodology of science is to be faithfully expressed, the essence of mathematics must be taught as part of science.

So learning theory suggests many plausible benefits to blending (or "integrating", if you insist) the ways in which mathematics and science are taught. These benefits are important for students, but unfortunately that argument is insufficient to bring about change. We all know that what really matters is politics.

It may just be that blending methods may be better politics than blending content. To infuse methods of science and mathematics into each other's instruction, one avoids the absolute need for careful coordination, with the inevitable controversy and painful compromise. Methodological issues such as exploration, group work, data collection, discussion, argument are activities that apply to all ages. The issues of symmetry or of dominant style also vanish: science teachers can stress the methods that suit science, using more quantitative and mathematical approaches as supplements whenever appropriate and to the extent that they prove effective. Similarly, mathematics teachers can use a blend of presentation and discovery method in whatever balance they find useful. Neither must feel threatened by domination from the other.

Finally, about instruction. By blending methodologies instead of content, one preserves the established traditions of essentially separate science and mathematics teacher preparation where scientific and mathematical content predominate. In school, teachers could engage in paired teaching, or team teaching, with the science teacher helping the mathematics teacher learn how to make productive use of exploratory assignments, while the mathematics teacher helps the science teacher see how to introduce quantitative, logical methods into science teaching. The system as a whole then builds on the strengths of the corps of teachers as a whole, rather than floundering on the inevitable weaknesses of individual teachers when confronted with the task of teaching an integrated science and mathematics curriculum.

So, in conclusion, the proposition I put before you for discussion is really quite simple: integrate how you teach before worrying so much about integrating what you teach.

Mathematics and Science Education: Convergence or Divergence

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Normal, IL

Mathematics and science education in American schools are currently at different points in the process of change. The transformations taking place in the two disciplines result from a wide variety of national reports (Dossey et al., 1988; International Association for the Evaluation of Educational Achievement, 1988; McKnight et al., 1987; Mullis et al., 1988; National Council on Excellence in Education, 1983; Steen, 1989). These studies, and others, have documented the shortcomings of the curricula in mathematics and science, the lack of parental support, and the national distaste for mathematics and science. The National Council of Teachers of Mathematics (NCTM) has responded to these challenges with its Curriculum and Evaluation Standards for School Mathematics (1989) and Professional Standards for Teaching Mathematics (1991). The American Association for the Advancement of Science responded with Science for All Americans (1989). The National Science Teachers Association (NSTA) is currently working on similar recommendations under its Scope, Sequence, and Coordination project, as well as through fledgling attempts to deal with reform in the elementary school curriculum (West, 1991). These extant and planned documents outline the broad curricular goals that our nation's schools should be striving to reach in mathematics and science and provide methods by which progress toward those goals might be assessed at both the student and school levels.

However, the paths and conceptions set for school mathematics and school science in these recommendations are not always convergent paths. This question of convergence or divergence is an important topic in both disciplines today. The resolution of the question, much like the resolution of the nature of a trial separation in a marriage, will have a great deal to say about the continued support each discipline will provide to the other. Mathematics education reforms from the early portion of this century have increasingly moved further away from direct ties with the science curriculum. One can cite several reasons why this has possibly happened. One is the number of other disciplines from business and the social sciences that have also called on mathematics for support in their growth and development. Second, mathematics as a discipline itself has seen rapid growth and expansion, especially as a result of expanded applications of computing technology. Third, the lack of consensus among science educators over the concepts and principles that should be included in the curriculum and developing in children at given age ranges has made the building of ties difficult. The present era of reform in mathematics and science education provides a new opportunity to seriously examine the nature of the relationship the two disciplines should have in their school level curricula.

Integrated Curricula

Calls for the integration of mathematics and science curriculum, such as the focus of this conference, are not new. They have surfaced frequently across the past century (House, 1990). The last major call came in the late 1960s from the Cambridge Conference on the Correlation of Science and Mathematics in the Schools (1969). This report called for the development of integrated mathematics-science curricula and the implementation of these in the schools. It also discussed the nature of teacher training, public relations efforts required, and the need for supportive instructional materials.

Zalman Usiskin (n.d.) and David Ost (1975) have identified a number of ways in which topics in a discipline or disciplines themselves might be related in the development of a curriculum. When people discuss curriculum building in mathematics or science they often use the term "integrated." Others talk of "integrated mathematics and science." What versions of integration of mathematics and science work are possible?

To some, "integrated" means that students simultaneously take courses in both mathematics and science and ties are made between content in the courses. This is called the **simultaneous model**. In other instances, the content from the disciplines involved are viewed as strands to be visited each year on some cyclical pattern. This results in a **braided model**, much like that in the spirally organized elementary school mathematics curriculum. A third approach is the development of a curriculum that focuses on specific topics in a given year, but topics may not be revisited for direct instruction in another year. This approach might be viewed as the **topical model**. A fourth method of considering the development of a curriculum drawing on both mathematics and science would be to select a set of unifying ideas which would be used to examine and relate the concepts, principles, and procedures from both disciplines. Such central ideas for the **unified model** might be sets, functions, and structures. A fifth approach is the full **interdisciplinary model** which completely merges the disciplines and draws from each when content is needed to move the topic of study forward on a given day or in a given unit of study.

At present we have ample examples of the simultaneous model taking place in our schools. However, there is little contact between teachers, or curriculum developers, to make the ties necessary for integrating mathematics and science. Careful development of examples of the braided, topical, or unified teaching of mathematics and science have not been attempted. One attempt at an interdisciplinary approach has been tried at the elementary/middle school level in the United States. The *USMES* (*Unified Science and Mathematics in Elementary Schools*) developed and implemented a unified program of mathematics and science education in public schools. However, due mainly to a lack of continued funding and large scale adoption, or adaption, of their materials, the project went by the wayside.

The thought of an integrated approach to school mathematics has a long history. The Committee of Ten's recommendations suggested the parallel teaching of algebraic and geometric content across the full span of mathematics teaching. Others on the committee wanted a broader form of integration than that provided by the simultaneous model (Sigurdson, 1962). E. H. Moore, in his retiring Presidential address to the American Mathematical Society in 1902, called for the use of functions as a unifying concept in secondary school mathematics and for an increased use of laboratory methods in the teaching-learning process. Moore's pleas for the use of the function concept were structured about the motivation that seeing such a seminal connection could have on students' acquisition of school mathematics.

George Myers and co-workers at the University of Chicago Laboratory School produced some curricular materials for the 1903-1904 school year. The first-year text was basically algebra and the second basically geometry. These materials remained in circulation to 1930, but were never widely adopted. The beginning of the century also saw some interest in the unification of mathematics and science. However, this movement was discouraged by a group of physics teachers who were worried about the mathematization of their subject (Sigurdson, 1962).

During the 1930s, integrated mathematics made another attempt to emerge in the textbooks of John Swenson. Swenson's materials used the function concept as a major unifying concept. He integrated geometry and trigonometry with his algebra. However, his texts were neither popular or widely adopted (Osborne & Crosswhite, 1970). During the 1960s, Vernon Price, Phillip Peak, and Phillip Jones attempted an interdisciplinary mathematics curriculum, but again it failed to gain wide acceptance, even though it was commercially promoted. The *Secondary School Mathematics Curriculum Improvement Study* housed at Columbia Teachers College produced a unified program for academically gifted students in the 1970s. This curriculum, *Unified Modern Mathematics*, is perhaps the most widely adopted program yet mounted in the area of mathematics.

At the present, the sequence of courses offered in New York secondary schools to prepare students for the Board of Regents' examination is structured about an integrated, interdisciplinary curriculum (Paul & Richbart, 1985). To date this attempt has been treated as an experiment by most of the other states and by most of the commercial publishing companies. Some wags have termed the attempts to develop the curriculum in an integrated fashion, the "permuted curriculum."

Structure of Subjects

Most of the present elementary programs of study in elementary school mathematics are constructed about the braided, or spiral, approach to curriculum development. This approach has come under attack in recent studies (Flanders, 1987; McKnight et al., 1987) for its slow progress and excessive review of material. While there is some indication that the 1991 copyright year texts have made some adjustments to address these findings there is still a tight spiral model underlying the elementary school mathematics curriculum. The NCTM Standards do not directly address the nature of the structure of the curriculum. However, the listing of specific strands for both the K-4 and 5-8 years and the overlapping of the content coverage in these strands strongly suggests that major organizational changes in the basic model for the curriculum have not significantly changed. The content in the new texts does reflect additional work being devoted to areas such as estimation, problem solving, probability, and statistics, as well as to the use of technology in computational settings.

Materials for the middle school level show a marked increase in pre-algebra material and in the applications of probability and statistics. The increased work in pre-algebra is noted in the solution of linear equations and work with the integers. It is perhaps that the greatest reaction to the Standards is noticed among the new textbooks. The focus is still very much on the development of a rather fixed linear sequence of concepts, principles, and skills. The main change has been a general tightening up of the material, a broadening of the coverage to address the recommendations of the Standards, and some attempt to address the calls for communication and connection in the curriculum.

In science, the trend in curriculum construction at the elementary grades is not as clear. There does not seem to be a clear pattern of topics or procedures that is deemed appropriate across more than one or two of the curricula available. The materials seem, instead, to focus on "doing" and "experiencing" in scientific investigation settings. This approach is quite consistent with the notion of treating "science" as a verb. The focus is far more on involving students in observing, conjecturing, experimenting, recording, and communicating.

Reform has moved quicker in mathematics due to the linear core of the mathematics curriculum, consensus among the schools about the goals and content of the school mathematics curriculum, and, finally, because the school curricula and teacher training have both placed a higher priority on the development of mathematical skills in children and in prospective teachers.

The Standards as a Key to Integration

The vision of school mathematics contained in the Standards provides a strong departure point for initial looks at integrating mathematics and science instruction for a portion of the time in the elementary school grades. Such an approach would be one that employed the interdisciplinary approach defined by Usiskin and Ost. Such an approach makes full use of either subject as the dual process moves forward. The possibility of such an approach looms larger today because of the increased emphasis given to number sense, measurement, estimation, probability and statistics, and the strand from patterns to functions. Each of these individual standard areas across the early grades provides strong latching points for the study of science as well as mathematics. Further, the joint study of the application of the concepts and procedures from these areas in both mathematics and science would strengthen the comprehension of the areas from both a mathematics and science viewpoint, while building strong connections between the two disciplines.

Additionally, time spent in the joint development of these areas would not be strongly viewed by either a mathematics-oriented or science-oriented teacher as having grievously crossed the invisible "turf lines" that sometimes create interference with attempts to integrate curricular areas.

All four of the basic process standards -- problem solving, communication, reasoning, and connections -- can thrive in a situation providing for both student growth in mathematics and science focused about the areas mentioned above. Additionally, the joint teaching should increase the amount of time available for the pursuit of these skills, another factor which has been seen to influence achievement in some of the international studies.

Several of the examples given in the expanded versions of the individual standards show immediate connections to science. Prominent among these at the K-4 level were:

> ... an investigation of eye color, concepts and estimations of measurements, use of measuring instruments, mapping, classification of objects, weather trends, and spatial perceptions. Examples given for grade 5-8 include relations of speed and time, maximizing volume, behavior of pendula, weather forecasting, shadows, perspective, and proportion. For grades 9-12, examples emphasize graphical representations and include problems of maximizing volume, the path of a projectile, limits of growth, forces, symmetry, and applications of mathematical modeling. (House, 1990, pp. 522-523)

Given these connections it is interesting to see the reactions that several of the elementary series have made in their initial publications following the issuance of the Standards. There is clearly an attempt to provide a great deal more emphasis on the collection and study of data, attempts to bring more content to the fore that provides opportunities for connections to the science curriculum, and attempts to provide the students with strong experiences -- though book guided -- to carry out the steps in the problem-solving process that is central to either mathematics or scientific investigations. Little reaction has been made to date by the secondary school mathematics curricular materials.

Barriers to the Achievement of Integrated Curricula

Given the calls for integration of mathematics and science education in schools, significant barriers stand in the way of the achievement of this goal. Unless thoughtful, and widely accepted, solutions are found to these challenges in a rather simultaneous fashion, there is probably little hope of the creation and wide acceptance of an integrated mathematics-science curriculum in American schools.

Curricular Materials

Key to the acceptance of any curricular reform is the development and wide acceptance of materials supporting that reform. As the above history of attempts to achieve some integration in mathematics education shows, the development of materials alone will not do the job. However, materials are a key to initiating a reform movement. Today, perhaps stronger than at any time in recent history, the "bottom-line" is a deciding factor on what materials are put into production. Thus, there would have to be strong, and undeniable, evidence that classroom teachers and schools were demanding the materials. The nature of the discussion at this conference shows that the level of demand in the field has not yet reached decibel level required to start the production process.

This hurdle is made more difficult through the lack of a clear picture in the science education field of the grade level student learning outcomes desired of all learners. In particular, there is not yet an active program working on the development of science outcomes for the primary and intermediate grades. At the secondary level, the present focus on reform is more on time-on-topic and getting students to take more science than it is on developing a clear focus of the content topics and level of proficiency expected of the nation's students. Even the Project 2061 materials from the American Association for the Advancement of Science reflect a lack of cohesion, as separate materials were produced for biological and health sciences, physical and information sciences and engineering, social and behavioral sciences, and technology. While there are connections tying the fields together, there is a wide diversity in the patterns of development reflected by the participants in the planning process for science education reform at this level. Perhaps a more coordinated view will emerge from this conference than has emerged to date. Such a view is necessary to the development of the materials.

Assessment

Key to any curricular initiative today is the spelling out of how one knows whether the attempt has reached its goals. The current focus on research at the national level in mathematics, science, and technology education appears to be moving slowly toward the integration of the subjects. While committees at the National Research Council have articulated goals for indicators in the areas of mathematics, science, and technology (Murnane & Raizen, 1988; Raizen & Jones, 1985), there is little professional consensus on what indicators would serve to measure progress in an integrated curriculum. The NCTM Standards (1989) provide guides for the development of assessments and curricular evaluations, but are incomplete in terms of detailing a specific program for assessing student progress and growth in an integrated setting. The Mathematical Science Education Board's April, 1991 National Summit on Mathematics Assessment should provide a starting point for discussion of potential paths to follow. However, given the president and Governors' goals for education, any curricular initiative needs to clearly focus on the way in which it should be assessed as part of the planning for the program's development.

Teacher Education

Central to the success of a curricular program is the degree to which teachers are comfortable with the materials, instructional patterns, and overall operation of the program. Large scale changes of direction in the offerings in school mathematics or science need to be accompanied by lead changes in teacher education at both the preservice and inservice levels. The magnitude of change signaled by an integrated mathematics and science program would require lead time to have teachers committed, educated, and prepared to step into the process. The many fiascoes that surrounded the introduction of "modern mathematics" programs in the 1960s serves as a strong indicator of the necessity of such planning. The recently developed NCTM Professional Standards for the Teaching of Mathematics (1989) should provide strong guidance to the development of programs of study.

Before such programs of teacher education can be developed, there must be clear ideas of the direction and nature of the materials, the underlying content in both the sciences and mathematics, and the intellectual skills that the teachers should be able to model and lead in instructional settings. Further, teachers will need to have the opportunity to experience the success and growth possible in such approaches, to be able to both feel comfortable in the classroom, as well as in articulating the value and goals of the process to parents.

Public Relations

Given the wide discussion of the lack of American student achievement in a broad international context in both mathematics and science, the argument that the teaching of integrated mathematics and science is better on the face of it will not do. Significant research will be needed to placate the critics, especially parents of students involved, in early work with the approach. This hurdle is much higher than it initially appears, because a failure in this area would doom successes in the other areas.

Careful development would require the acquisition of solid professional association support, the involvement of strong leaders from the mathematics, science and education communities. Further, outstanding, experienced teachers would be needed in each of the locales where the programs would be initiated.

This challenge for public relations will also surface in dealing with members of the various disciplines involved in mathematics, mathematics education, the sciences, and science education which will also react to protect their "turf." Within mathematics, many will react that mathematics is no longer the "maiden" of the sciences, but also now serves business and economics and the social sciences. Similar challenges will come from areas of the sciences that feel that their influence is weakened by the merging of their area with mathematics and other areas within the sciences.

Summary

Integrated mathematics and science programs for school curricula have a strong support at the discussion level. However, for the call of the Loreli to reach the stage of actualization in programs affecting children, significant challenges must be addressed. The degree to which a carefully constructed program for the development of sample integrated programs, research agenda to document their efficacy, production of materials to support teachers, programs of professional development for teachers, and plans for developing public support are developed, implemented, and monitored will, in the end, determine the probability of the existence of integrated programs of mathematics and science education in American schools.

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Breaking What Barriers Between Science and Mathematics?
Six Myths from a Technological Perspective

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Students in junior high and high school dealing with integration and differentiation without ever dealing with f(x)? Junior high students measuring angles of hip and knee to find out if those angles relate to how fast you can run? Computational Science? I've heard of Theoretical Science, Experimental Science but Computational Science? Such programs as these from the Technical Education Research Centers and The Cornell National Super Computer Facility are breaking the barriers between science and mathematics. What are those barriers and how can they be broken? First such barriers are greatly myth. A myth according to the American Heritage Dictionary is "a fiction or half truth, one that forms part of the ideology of a society." As you will see as we proceed through the six myths there are some truths in them but they are, I believe, truly myths.

The Great Myth: There is a barrier between science and mathematics. The following six myths indicate how technology can blast through the barrier between science and mathematics.

Myth one: The myth of analysis before synthesis. If you examine the common curriculum in high school and junior high school you realize very quickly that the patterns developed still come from college and university curriculum. In that traditional curriculum, students concurrently take calculus while they are taking physics. To properly understand physics you must have the analytic procedures of differentiation and integration. But recently a little experimentation using technology has indicated that student 'hands-on' experiences can provide solid conceptual understanding of differentiation before analytic techniques. For the first time we can introduce calculus, both differentiation and integration, without the seeming prerequisite skills of algebra. Nemirovsky (1991) reported using a motion detector attached to an analog to digital converter connected to a computer. Students were able to explore distance-time relationships from a speed-time graph constructed from their own body motion as they moved toward or away from the detector. All the common misconceptions of displacement, slope, and direction of the integration or differentiation graphs were exposed. In subsequent lessons these misconceptions were removed by experimentation and further reflection. Later as analytic differentiation was introduced, students realized and related the connection to real events.

Myth two: The myth of the word problem. Word problems seem to remain the proof of concept for students to apply their knowledge on real world problems. But are these real world problems? Using a video disk or tape, Sherwood (1991) has reported on a series of very real world problems. In the "Jasper Woodbury" series, students in junior high math classes explored time, distance, and cost relationships by observing a video tape of Jasper motoring up river to buy a new boat. Not only did the students have to solve ratio and algebraic problems but first they also had to find the data embedded in the story. The use of embedded information and cooperative learning in using such videos provides truly real world applications and again integrates science and math problem solving.

Myth three: The myth of science as reality, math as numbers and formulas. To destroy this myth we can observe the program SuperQuest. High school students are starting to learn of computational science through programs such as SuperQuest from the Cornell National Super Computer Facility.

> Take the case of Brian Odom a participant in a team from Texas. "Odom, a junior at Clear Lake High School in Houston, is working on artificial intelligence. Clear Lake's team, coached by teacher Judith Tarrant, is the only one drawn from the general student body of a public high school; the other three are products of school programs geared toward science studies or gifted students. Rather than emulating other approaches -- neural networks or knowledge-based systems -- Odom is trying to build a model somewhere in between. "The program mimics two simple brain functions, and builds a tree of decisions and comparisons based on them," he explains. "It can learn from its experience." To test and develop his computing method, Odom is using it in a program designed to recognize patterns -- specifically, alphabetic characters. His SuperQuest project has entailed expanding the program and transferring it into the FORTRAN programming language.

Computational science, in which students explore muscle action of the eye or acoustics of a high school auditorium is an old but new science with just developing pedagogy. The powerful computational techniques of the computer allow students to build a new integration of science and mathematics.

Myth four: The six simple machines or taking square roots. All too often we're rooted, (pun intended) in the tradition of our pedagogy. As a junior high school teacher I would control the class with threats of taking square roots. The greater the infraction the more digits. Later in developing elementary science curriculum we were often asked where in our curriculum were the six simple machines. The history of the inclusion of the six simple machines in science curriculum provides an interesting insight. A graduate student completing a dissertation carried out a survey of practical topics that should be included in the new science curriculum. Science educators and laypersons replied that students should know the principles of the wheel and axle, of pulleys, and of inclined planes ... all the six simple machines. This latest need was incorporated into curriculum from the recently completed dissertation at that time. The time? 1917. If you recall the state of technology of the teens, you may recall that inclined planes were common loading dock extensions. Pulleys and block and tackles were common tools for moving heavy objects. If you look at some of the very old buildings you'll see those slanted loading docks and hooks for the block and tackles still embedded in the building overhangs. Today the six simple machines are replaced by fork lifts and their counterparts, yet we still teach the six simple machines. In math we learned an algorithm that is burned into my long term memory to this day. Yet even a five dollar hand calculator has that button that takes square root in less than a second. Are simple machines and square roots passe? No, but the algorithms and reasons we teach what we teach in our programs must be examined. In preparing this paper I asked teachers what might prevent them from integrating science and mathematics into their current curriculum. The main reason by far was that "I can't teach all that I need to teach now." Yet have we examined that intersection of math and science to find out if we can benefit from the leverage of integrated teaching and have we examined all our math and science curricula to find if we should remove or modify our use of modern technology to help us teach more efficiently?

Myth five: If it moves have the students graph it. This myth sponsors two of the most famous Murphy's laws of graphing "The last set of ordered pairs plotted will be off the paper" and "You will have done the entire graph in ink." Though these laws' are facetious, they do point out one of the strongest problems of graphing in science and mathematics. The time and effort to hand graph a set of data may so intensely occupy teachers and students that the results or conceptual learning that should proceed from the graphing may be lost. To destroy this myth several researchers around the country have been using graphing programs or video-computer integrated packages to help. One such effort is underway at the Technical Education Research Centers with a project called TapeMeasure.

> TapeMeasure is a system that allows students to make measurements on a videotape. They can choose particular frames to measure by using a VCR-like interface that allows them to advance the tape a frame at a time or by choosing a particular named video segment from a directory. The measurement tool palette contains a ruler, a stopwatch, and a protractor as well as two mark-up tools that students use to prepare a set of video frames for measurements. The system was used in a 7th and 8th grade urban classroom in an investigation of the variables that affect running speed.

The designers combined the program with a common analytic graphics package "Cricket Graph" and had students drawing conclusions of running speed from scatterplots and correlation diagrams that could be regraphed in seconds.

Myth six: The myth of the ordered pair. At an NSF institute many years ago, we presented participants with a word problem that contained more information than students needed to solve the problem. Several professors from a foreign country conferred briefly and then told us that the problems were wrong, not the answers but the problems themselves. They pointed out that putting too much information in a problem would be confusing to students and that we should only include enough information for students to use to solve the problem. As strange as that sounded then, it is just as bad now that we have technology and still create sample files that just have the right number of ordered pairs. At NARST last year, David Jackson of the University of Georgia and Billie Edwards of the Detroit Public Schools and I reported on a five year project of using microcomputers to aid in teaching graphics in both math and science. We designed our own graphics program to introduce students to graphical problem solving. An experiment designed to investigate the optimal balance between flexibility and feedback in the design of such software was carried out and relationships of the design principles in the graphing program to general ideas in the philosophy of science education and of the design of computer artifacts were reported. Building on the demonstrated success of microcomputer-based labs in helping science students to understand line graphs representing phenomena of motion, we generalized the use of computer-assisted graphical data analysis to involve students with relatively weak math and science backgrounds in using several kinds of graphs to solve problems in several different domains. Extensive observations and unstructured interviews with students in the process of solving problems led to general principles of effective teaching about graphs in relation to real classroom teaching.

Research on problem solving has traditionally been restricted to studies of a very small and often unrepresentative sample of students, typically conducted in a controlled laboratory environment. The appropriate application of microcomputers has the potential to circumvent the artificial restrictions on research imposed by the time- and labor-intensive nature of traditional methods, thus providing for greater generalization of results to educational practice and possibly generating insights into problem-solving processes which emerge only at a macroscopic level. We carried out an investigation of the potential of computerized data gathering and analysis based on sequence analysis in the natural sciences to open up research on problem solving to studies involving a very large sample of students, representative of a population of great interest, in a more typical classroom setting. We used a graphics program specifically designed for student learning and a data set that included many variables for several problems. To solve the problems presented, students first had to determine which set of data were the most appropriate and what kind of graph should be developed. Once having constructed one graph it was a simple mouse click to have a different type of graph produced. Using such a graphics procedure we were able to reduce a three week unit to one and one half weeks and an improvement of comprehension from 40% by 45% of the students to 80% by 90% of the students. Perhaps the most telling comment came from teachers in the schools who related that students were skipping classes except the computer graphing class.

The Great Myth Again: There is a barrier between science and mathematics. Again as with all myths there is truth in this one. Also there does not need to be a barrier. In each of the examples above, technology can be used to blast through the barriers. From pocket calculators to video disk-computer devices, technology can be such a tool. Just as textbooks were introduced as tools over a hundred years ago, this technology will cause us to rethink our pedagogy. It will offer us the opportunity to make quantum leaps in our interaction. But just as any technology is just a tool, it will require fundamental changes in our ideas of what we teach, how we teach and what's important to teach. In examining these notions we can deliberately use technology to help remove barriers or we can ignore or misuse this tool. The choice is ours, where are the barriers?

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Video Environments for Connecting Mathematics, Science and other Disciplines* [1]

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Participants in this conference have been asked to explore the issue of integrating mathematics and science instruction. Since we are currently conducting a considerable amount of work in fifth and sixth grade classrooms (e.g., CTGV, 1990; Goldman, Vye, Williams, Rewey & Pellegrino, 1991; Van Haneghan, Barron, Young, Williams, Vye & Bransford, in press) our primary goal is to explore this issue from the perspective of these grade levels. Our argument will be that the integration of mathematics and science can be highly desirable not as an end in itself but as a means to achieve other goals.

The goals that we want to achieve are to help students experience the excitement and importance of mathematical and scientific inquiry, to realize that it is within their potential to engage in such inquiry, and to offer them the kinds of experiences that will set the stage for lifelong learning. It has been our experience that, given such goals, it becomes natural to begin to integrate not only mathematical and scientific information, but to also help students make connections between these areas and others such as technology, history, social studies and literature (e.g., Bransford, Sherwood & Hasselbring, 1988). The importance of connecting mathematics instruction to other curriculum areas and to events outside the classroom, and of helping students make connections among mathematics, science and technology, has been emphasized by the National Council of Teachers of Mathematics (1989) and the American Association for the Advancement of Science (1989).

We begin this paper by discussing why it is valuable to help students integrate their knowledge across subject areas. We then note important barriers to such integration, the most notable being that this approach to instruction requires a great deal of knowledge on the part of teachers. We end by discussing an approach to instruction that has the potential to overcome these barriers, and we provide examples of the approach.

*An expanded version of this manuscript has been published in M. Rabinowitz (Ed.). (1993). Cognitive Science: Foundations of Instruction (pp. 33-55). Hillsdale, NJ: Lawrence Erlbaum Associates.

1.0 Some Reasons for Encouraging Knowledge Integration

1.1 Instructional Time

There are several arguments that provide a rationale for the design of curricula that can help students integrate their knowledge across subject areas. One involves the issue of making better use of the time available during school. During the past several years, members of our center have had the opportunity to meet with groups of mathematicians, scientists, geographers, historians, reading specialists, artists, musicians and so forth. Invariably, each group would like more time for instruction, which means that less time is available to teach something else.

We remember a cartoon published several years ago (we think by Gary Trudeau) that illustrates the "time for instruction" dilemma. It begins by mentioning test scores which indicate that American students are terrible at geography. We then see a teacher who is extremely upset by this fact and vows to spend the rest of the year correcting this problem with his students. The cartoon ends with someone saying to the teacher: "But you're the mathematics teacher." Unless the teacher can integrate the teaching of mathematics with the teaching of geography, something is going to be lost. Elsewhere, we argue that such integrations of knowledge are possible (e.g., Bransford, Sherwood & Hasselbring, 1988).

1.2 Inert Knowledge

A second, more fundamental reason for integrating inquiry across subject areas relates to a problem discussed many years ago by Alfred Whitehead (1929) and re-emphasized in the past decade: the inert knowledge problem. Whitehead noted that students are often asked to learn individual concepts and procedures that they can remember when explicitly asked to do so -- when given a multiple choice test, for example. Nevertheless, when asked to solve problems where these concepts and procedures would be useful, the students often fail to do so. Their knowledge remains inert.

1.2.1 Some Illustrations of Inert Knowledge

We can clarify the problem of inert knowledge by considering an interview with a fifth-grade student whose knowledge of geometry is destined to remain inert.

Interviewer (I): Do you know anything about Geometry?

Student (S): Sure. We study it in school.

I: What do you do in Geometry?

S: Measure angles. We use a protractor.

I: Why do people measure angles?

S: To find out if they are obtuse or acute and stuff.

I. Why is it useful to know that?

S: To pass the fifth grade.

Other parts of the interview revealed that this student had learned many facts and procedures that are relevant to geometry. She knew the difference between acute and obtuse angles, could use a protractor and had even memorized the definitions of a point and a line. However, we could find no evidence that she had the slightest idea about actual uses of geometry. We also believe that this is typical of most students (and even of adults).

A common offshoot of the kind of instruction that produces inert knowledge is a dislike for the subject matter. Pellegrino (1990) asked college freshmen in his class to describe their feelings about mathematics and to interview their friends about the same topic. Almost to a person, there was a strong dislike for mathematics -- even by people who were getting A's in courses such as calculus. A complaint voiced by nearly every student was the seeming irrelevancy of the subject matter for anything except a course grade. For example, they had no idea why one would ever need calculus.

Problems of inert knowledge also abound in science classes. A number of researchers have shown that students often begin instruction in physics with misconceptions about natural phenomenon that affect how they think about them (e.g., they intuitively adopt an Aristotelian rather than Newtonian perspective on the world). Ideally, science courses influence how people view their world. Unfortunately, this often does not happen. Students learn to deal with the technical definitions and formulas during their science courses but they tend to leave these courses with the same misconceptions that they held when they started (e.g., see Clement, 1987; Minstrell, 1989). In short, the technical knowledge acquired in science classes remains inert. It has no effect on how the students think about their world.

At a broader level, we argue that the typical compartmentalization of courses can lead to inert knowledge because it inhibits people's tendencies to apply knowledge from one area to other areas:

> Currently, most students who take courses in the humanities, social science and physical science learn about each area as a separate entity. They rarely have the opportunity to apply ideas from one area to a problem that is also being addressed from the perspective of the other areas. Students therefore lack a common ground for comparing the effects of adopting different perspectives. Because of the specialized nature of their training, most college professors share a similar fate (Bransford, Sherwood, Hasselbring, Kinzer & Williams, 1990, pp.134).

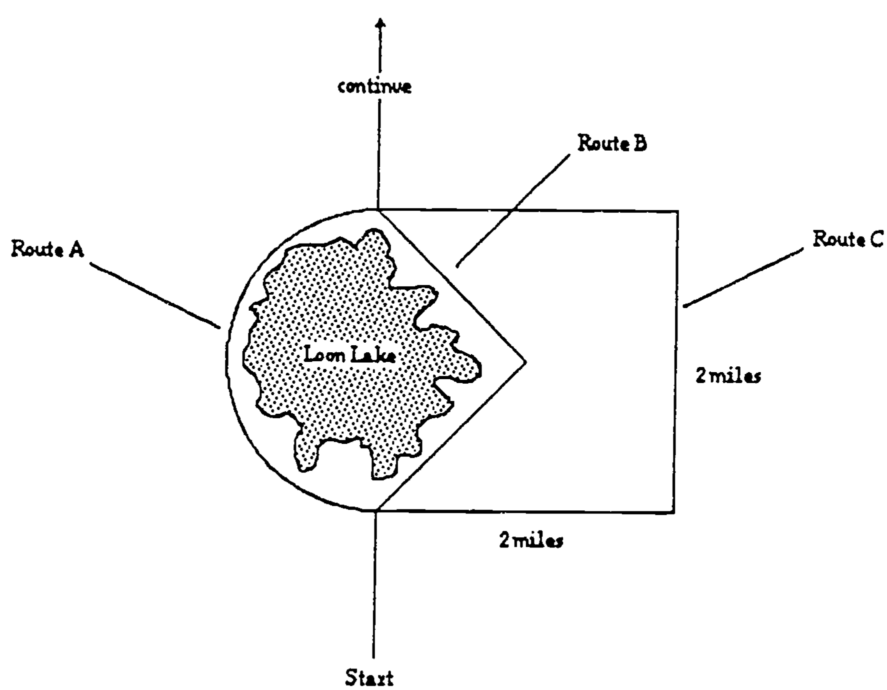
A number of laboratory and classroom-based experiments, plus new formulations of the nature of knowledge, have helped educators better understand how to avoid inert knowledge (e.g., Bransford, Goldman & Vye, in press; Bransford, Sherwood, Vye & Rieser, 1986; Gick & Holyoak, 1980, 1983; Simon, 1980). Basically, students need a deeper understanding of why various concepts and procedures are useful, and they need the kinds of experiences that will allow them to develop organized knowledge structures that are richly interconnected (e.g., Chi, Bassok, Lewis & Glaser, 1989; Resnick & Klopfer, 1989). When one attempts to create such experiences for students, it becomes natural to use information from one domain to clarify another and vice versa. The areas of science, mathematics and engineering constitute a mutually supportive domain set.

1.2.2 Making Knowledge Less Inert

It is instructive to consider some illustrations of techniques for helping students understand the value of the knowledge that they are learning and its connections with other aspects of their knowledge.

Geometry: Interviews that we have conducted suggest that geometry becomes more meaningful when students are introduced to issues often faced by engineers who are trying to measure and map the environment, or by people who are trying to locate a particular source by means of triangulation and must then navigate in order to find that source. We are beginning to design several videodiscs for geometry instruction that are based on the assumption that an introduction to these areas of application can help students transform their impression of geometry from one involving the (sterile) measurement of triangles, circles, squares, etc. (see the preceding interview with the fifth grader) into something that is more inspiring; namely, the powerful idea of using the "secrets" (invariant properties) of basic shapes (e.g., triangles, circles, squares) to measure, locate, and communicate about important aspects of the world.

Figure 1



One simple example of a way to make the value of geometry clearer to fifth and sixth graders (as well as adults) is to imagine that the students have access to a map that includes configurations such as the one shown in Figure 1. Their task is to find the shortest route (i.e., routes A, B, C) in order to rescue someone. However, only some distances have been determined. Students can see how applying basic principles of geometry would allow them to determine the value of key unknowns.

Science Concepts: Concepts in science also become clearer when students can see uses for them. We have been able to help students understand the usefulness of a concept such as density by creating video scenarios that involve objects that are supposedly pure gold (e.g., the golden idol in "Raiders of the Lost Ark" or a "golden statuette" used in one of our video stories [CTGV, 1991]). How could one tell whether the objects are actually made of gold or made of something else? In order to solve such problems, students have to determine the mass of the objects and then the volume (Archimedes faced a similar challenge and solved it with his insight about displacement as a way to measure volume). Most high school students with whom we have worked had very little idea about how to approach these problems even though they had studied density and displacement in their science classes (another example of the inert knowledge problem). After being helped to understand the video scenarios, students report a much clearer idea of the importance of discoveries such as density and displacement. Prospective science teachers also needed help in this regard (CTGV, 1992).

Authenticity and Multiple Perspectives: In the preceding illustrative cases, students are exposed to authentic and meaningful situations in which mathematical and scientific principles play a pivotal role. We and others (e.g., Brown, Collins & Duguid, 1989; CTGV, 1990) have argued that such meaningful applications of domain knowledge are critical to avoiding the inert knowledge problem.

Being able to view a situation, principle or problem from multiple perspectives is a second key factor in avoiding the inert knowledge problem. The compartmentalization of instruction often results in a similar compartmentalization of students' and teachers' knowledge. A major challenge is to find ways to help students develop the ability to think about events from multiple points of view (e.g., from the perspective of a mathematician, scientist, artist, etc.). Elsewhere we discuss data which indicate that the tendency to approach problems from multiple perspectives can be enhanced by relating different ideas to a common "case" or set of examples (Bransford, Vye, Kinzer & Risko, 1990). This idea of creating interesting cases that can be viewed from multiple perspectives is explored in more detail later in our discussion of the Jasper series.

1.3 The Importance of Creating Mathematical Models and Using Technological Tools

In addition to attempts to deal with the problem of limits on instructional time and the problem of inert knowledge, a third reason for integrating mathematics and science instruction is that the two areas complement one another. The idea of quantifying information and of developing mathematical models in an effort to explain important phenomena is ubiquitous in science, business, engineering and a host of other fields. The idea of using technology-based tools to create models of phenomena is becoming so commonplace in science and business environments that it seems inconceivable to think about instruction in the absence of such technology.

Technology is also a powerful tool for effective communication of ideas, which is important for all areas of inquiry. The availability of desktop multi-media programs makes it possible for students to publish text, animations, still pictures, moving video clips and so forth. In order to fully develop students' communication skills, it can be useful to go beyond the areas of science and mathematics and to seek insights from the people with a knowledge of the writing process (e.g., Hull, 1989).

2.0 Barriers to Knowledge Integration

Despite the potential advantages of knowledge integration, there are clear barriers to this approach to instruction. A major barrier is that it places an exceptionally heavy burden on teachers. It is very difficult to develop the content knowledge and pedagogical skills necessary to be either an outstanding science teacher or mathematics teacher. To be able to do both well is extremely difficult. A related problem is that there is very little time during school hours for teachers to learn about new instructional ideas and to discuss these ideas with one another.

One reason why the goal of integrating math and science instruction places a heavy burden on teachers is that the educational goals of these two domains are not necessarily identical. For example, it seems clear that scientific inquiry provides an excellent domain for helping students understand the value of mathematics as a tool for inquiry. Nevertheless, the mathematics educators whom we know also want students to learn to explore mathematics as a formal system as well as use it as tool for exploring other issues (e.g., Schoenfeld, 1988, 1989). Many science teachers know how to use mathematics as a tool but do not deeply understand it as a formal system.

Related to the preceding point is the fact that good mathematics teachers help students develop deep, conceptual understandings of mathematical concepts and procedures. The ability of a science teacher to use mathematics to solve a problem does not guarantee that he or she knows how to help students understand the mathematical knowledge at a conceptual level. As a simple example, imagine a sixth grade science teacher who is using a cylinder of some unknown metal to teach about the concept of density and, in the process of calculating its volume, needs to teach the students to use the value pi. It is one thing to teach students that pi is approximately 3.1416; it is quite a different matter to help students understand that pi represents the ratio of circumference to diameter and constitutes an invariant property of all circles. Good mathematics teachers know how to develop conceptual (rather than mere procedural) understanding for a wide variety of concepts (e.g., NCTM, 1989). To develop the knowledge and skills needed to teach conceptually is no trivial matter.

The preceding argument can be made in reverse if one considers the possibility of having mathematics teachers teach science. It should not be difficult for people with strong backgrounds in mathematics to learn to deal with the formal aspects of science such as the basic principles taught in high school physics. Nevertheless, there are extremely important differences between approaches that teach students to deal with formulas (e.g., F = MA) and those that help students understand at a conceptual level. We noted earlier that a number of researchers have shown that students often begin science instruction with misconceptions about natural phenomenon (e.g., they assume an Aristotelian rather than a Newtonian world) and that these misconceptions persist if students are taught only to deal with facts and formulas (e.g., see Clement, 1987; Minstrell, 1989). In short, there are important gaps between "learning to do the calculations" and understanding the concepts that are being taught.

The fact that most school schedules allow only a limited amount of planning time for teachers makes it extremely difficult for them to increase their abilities to integrate math, science and other subject matters -- especially given the fast-paced changes in these areas. One solution to this problem might be to create classroom-based events that allow teachers to learn along with their students. In our discussion of teleconferencing that appears later, we discuss some possibilities for achieving this goal.

3.0 Anchored Instruction as an Approach to Integrative Collaborative Inquiry

During the past several years, we have been exploring the potential of anchored instruction (CTGV, 1990) to overcome some of the barriers to knowledge integration discussed previously. One of the advantages of the anchored instruction approach is its potential to facilitate collaboration among specialists in a variety of domains. When this approach is augmented by telecommunications and teleconferencing, it provides a way for teachers to learn along with their students.

3.1 Common Grounds for Collaboration: The anchored instruction approach that we have been developing involves the use of specially designed, inquiry-based video environments. They serve as "anchors" which provide a common ground for exploration and collaboration. These environments are very different from the typical educational video that usually shows a lecture on videotape. Our environments depict real-life adventures that can be explored at many levels. They are designed to allow teachers as well as students to connect knowledge of mathematics, science, history and literature by exploring the environments from different points of view.

3.2 The Need for Multi-Disciplinary Teams: The video environments and the materials and activities to accompany them are being developed by our Learning Technology Center at Vanderbilt. Our center is multi-disciplinary and includes specialists in cognitive science (including cognitive development), education, mathematics, the sciences, and computer and video design. In effect, our center is designed to provide the kinds of collaborative efforts that seem necessary in order to keep instruction from falling into the same disciplinary boxes that have existed in the past.

One of the advantages of our multi-disciplinary group is that many people who work on a project are not necessarily experts in the area. Thus non-scientists and scientists work together, non-mathematicians and mathematicians work together. The experts in each area play a crucial role, of course, but they also have a disadvantage. They are often so close to their subject matter that they have lost their intuitions about what is clear and unclear to novices. Our team approach helps us find the kinds of examples and experiences that make areas of inquiry make sense.

Our center also works very closely with teachers and their students. One of our projects involves fifth and sixth grade classrooms in 9 different states (Pellegrino, Heath, Warren & CTGV, 1991). This is providing us with a great deal of valuable information that comes from formal evaluations of students' problem solving, from teacher's insights about ways to do things better, and from a deeper understanding of the constraints on teachers and students that affect what they do. The need to "cover the existing curriculum" and to worry about scores on standardized tests are two examples of constraints. The lack of time available during school hours for planning new lessons is another important constraint.

3.3 Theoretical Rationale: As noted earlier, the videodisc environments that we have created are designed to allow students and teachers to experience the kinds of problems and opportunities that experts in various areas encounter. Theorists such as Dewey (1933), Schwab (1960) and N. R. Hanson (1970) emphasize that experts in an area have been immersed in phenomena and are familiar with how they have been thinking about them. When introduced to new theories, concepts and principles that are relevant to their areas of interest, the experts can experience the changes in their own thinking that these ideas afford. For novices, however, the introduction of concepts and theories often seems like the mere introduction of new facts or mechanical procedures to be memorized. Because the novices have not been immersed in the phenomena being investigated, they are unable to experience the effects of the new information on their own noticing and understanding. Under these circumstances, their knowledge tends to remain inert.

The general idea of anchored instruction has a long history. Dewey (1933) discussed the advantages of theme-based learning. In the 1940's, Gragg (1940) argued for the advantages of case-based approaches to instruction -- approaches that are currently used quite frequently in areas such as medicine, business and law (Williams, 1991). Each of our videodisc environments can be viewed as a case that provides a common ground for collaborative exploration.

4.0 An Environment for Anchored Instruction

For purposes of this paper, we will try to illustrate the concept of anchored instruction by focusing on one of our center's videodisc projects, our *Jasper Woodbury Problem Solving Series*. The primary focus of the Jasper series is on mathematical thinking. However, we also designed the series so that there is considerable potential to integrate mathematical and scientific inquiry. In addition, it is designed to help students create links to history, literature and other areas. If time permits during our presentation at the conference, we will also discuss our

Scientists-in-Action Series which focuses primarily on science rather than on mathematics.[3] Like the Jasper series, it is designed to permit a number of cross curricular links.

The Jasper series consists of a set of specially designed video-based adventures that provide a motivating and realistic context for problem solving and reasoning. Each video in the Jasper series has a main story that is 14 to 18 minutes in length. At the "end" of each video narrative, one of the characters (Jasper in the first episode; Emily in the second, etc.) is faced with a realistic problem that has to be solved. Students are challenged to solve the problem.

Table 1

Seven Design Principles Underlying the Jasper Adventure Series

Design Principle	Hypothesized Benefits
1. Video-Based Format	A. More motivating. B. Easier to search. C. Supports complex comprehension. D. Especially helpful for poor readers yet it can also support reading.
2. Narrative with realistic problems (rather than a lecture on video)	A. Easier to remember. B. More engaging. C. Primes students to notice the relevance of mathematics and reasoning for everyday events.
3. Generative format (i.e. the stories end & students must generate the problems to be solved).	A. Motivating to determine the ending. B. Teaches students to find and define problems to be solved. C. Provides enhanced opportunities for reasoning.
4. Embedded data design (i.e. all the data needed to solve the problems are in the video)	A. Permits reasoned decision making. B. Motivating to find. C. Puts students on an "even keel" with respect to relevant knowledge. D. Clarifies how relevance of data depends on specific goals.
5. Problem complexity (i.e. each adventure involves a problem of at least 14 steps)	A. Overcomes the tendency to try for a few & then give up. B. Introduces level of complexity characteristic of real problems. C. Helps students deal with complexity. D. Develops confidence in abilities.
6. Pairs of related adventures	A. Provides extra practice of core schema. B. Helps clarify what can be transferred and what cannot. C. Illustrates analogical thinking.
7. Links across the curriculum	A. Helps extend mathematical thinking in other areas (e.g. history, science). B. Encourages the integration of knowledge. C. Supports information finding and publishing.

They have to generate the relevant sub-problems comprising the overall problem and decide on the relevant data and mathematical procedures. All the data needed to solve the problems are provided in the video, and the problem to be solved is very complex (see Table 1 for a description of the full set of design principles underlying the Jasper series). Each Jasper adventure also shows a conclusion to the adventure that students can watch after they have solved the problem themselves.

The Jasper adventures are organized into pairs; both members of each pair involve similar types of problems (i.e., trip planning for the first pair, using statistical data to develop a business plan in the second pair; making decisions from data gathered from meaningful uses of geometry in the third). There are also many links in each video that allow students and teachers to extend their explorations across the curricula. We discuss these in more detail later on.

4.1 **A Description of *Rescue at Boone's Meadow*:** The first episode of the pair of trip planning videos, *Journey to Cedar Creek*, has been described elsewhere (e.g., CTGV, 1991). We will describe the second episode *Rescue at Boone's Meadow*. This episode opens with a view of Larry Peterson flying his ultralight airplane. We soon learn that Larry also teaches others to fly and we see him with one of his pupils, Emily Johnson. Through a series of lessons, Larry introduces Emily (and the viewers) to a variety of information about his ultralight such as fuel capacity, speed, payload limits, how the shape of the wing produces lift and so forth. Emily learns her lessons well and soon flies solo. To celebrate, she and Larry join Jasper Woodbury at a local restaurant.

At the restaurant, we learn that Jasper is planning to take his annual fishing trip. He is going to drive to Hilda's (where she has her house and runs a gas station) and then hike approximately 15 miles into the woods to Boone's Meadow. The conversation reveals other information such as the fact that Larry flew his ultralight to see Hilda the previous week and set it down in the field beside her house. At the end of the restaurant scene both Larry and Emily weigh themselves. Data from this as well as other scenes become relevant later on.

As the adventure proceeds we see Jasper on his fishing trip. As he is eating his catch he hears a shot and goes out to investigate. He finds a wounded eagle and uses his CB radio to call for help.

Hilda answers Jasper's call and relays the message to Emily. Emily consults with Doc Ramirez, the veterinarian, who supplies additional information about eagles, distances, etc. His map reveals that there are no roads between Cumberland City (where Larry and Emily are located) and Boone's Meadow (the location of Jasper and the Eagle). The doctor has another patient to attend to but emphasizes to Emily that time is of the essence in rescuing the eagle.

The adventure ends with a view of Emily posing the problem that confronts her: "What is the fastest way to rescue the eagle and how long will that take?" This is the challenge that is presented to the students. It is at this point that students move from the passive, televisionlike viewing to an active generation mode. They must solve Emily's problem; to do so they have to generate the sub-goals and constraints that she must consider to find the fastest way to rescue the Eagle. All the data needed to solve the problem were presented in the video. Students go back and search for the information they need.

The problem looks deceptively simple, but in reality there are numerous possible solutions and each involves many subproblems. For example, once students decide on a route, they must also identify a specific agent (person) and a vehicle (car, ultralight, or hiking). Then students must determine the feasibility of the route by evaluating the plan against multiple constraints: landing area, payload, and the range of the vehicle. If the ultralight is in the plan, range is determined by a complex calculation involving fuel capacity, fuel consumption, and distance. In addition, the ultralight's range can be extended by carrying an extra gallon of gas. But carrying the extra gas and the cargo box will affect payload.

Overall, there are a number of possible (and impossible) solutions and some are faster than others. In order to adequately explore and discuss the possibilities, students generally need three or four class periods. Even college students find the Jasper problems challenging (e.g., see Van Haneghan et al., in press). Data showing the effects of working with Jasper on students' abilities to generate and solve complex problems are discussed elsewhere (e.g., Goldman et al., 1991; Pellegrino et al., 1991; Van Haneghan et al., in press).

4.2 Analogs and Extensions

In addition to the major problem for each Jasper adventure, we are also designing additional print and video materials that present analog problems as well as extensions.

Analogs: Analogs are problems that are very similar to the original Jasper adventure. The purpose of the analogs is to invite students to think about the implications of slight changes in the adventure. For example, students may be asked to imagine that Emily had access to a different ultralight with different features (fuel capacity and consumption, payload limits, etc.) Given this set of constraints, is there a different flight plan that would be more ideal?

Students can also be asked to consider whether Emily's solution with the original ultralight would have worked if there were a 6 mile per hour headwind while she flew from Cumberland City to Boone's Meadow (it wouldn't). Problems become increasingly tricky if Emily encounters a wind from the side rather than a direct headwind. Now students can see the need for trigonometry and the concept of vectors. We do not expect fifth and sixth grade students to master such information. Nevertheless, by understanding how this knowledge fits into the greater scheme of things, students stand a much better chance of wanting to learn about these areas later in their academic careers.

Extensions: In addition to Jasper analog problems are extensions that allow students to see how the planning involved in Emily's rescue is similar to the planning involved in other events. One extension problem for *Rescue at Boone's Meadow* involves a consideration of the planning that Charles Lindbergh had to do in order to prepare for his flight from New York to Paris. Another involves the planning required for the first trip to the moon. By exploring these issues, students learn history, geography and other subject matters at the same time that they receive increased opportunities to think mathematically. We believe that the mathematical analyses of the planning involved in these historical events provide students with a richer understanding than they receive by merely reading about what happened and when the event occurred.

Other types of extensions provide the opportunity for integrating a number of different areas in mathematics and science. At Vanderbilt University this summer, our Jasper group will work with professors, graduate students and undergraduate students from various disciplines (e.g., physics, biology) in order to create materials that can help teachers and students develop a deeper scientific understanding of many of the events depicted in the Jasper adventures.[4] In *Rescue at Boone's Meadow,* an exploration of principles of flight is an obvious area for further inquiry. So is an examination of radio waves and how they can be transmitted without wires (Jasper uses his CB radio to tell Hilda about the wounded eagle who then contacts Emily by phone). An examination of endangered species is also made relevant by the eagle in the story. We especially want to develop extension materials that allow students to perform their own experiments in order to draw conclusions (e.g., Schwab, 1962). An example involves the construction of various kinds of model planes that students could experiment with to better understand concepts of aerodynamics. Another example might involve an investigation of the kinds of materials (e.g., lead) that block various types of radio waves.

Other Jasper adventures provide opportunities that allow students to learn about, and perform experiments on, concepts of flotation, density, leverage, recycling, statistical probability and so forth. The possibilities continue to expand as one begins to work with people from a variety of different areas and disciplines. By creating HyperCard stacks that all relate to a common Jasper anchor, experts who might never have the time to meet together can share their ideas. Students are able to share their ideas in similar ways.

Our ultimate hope for the Jasper series is to have it set the stage for student-generated activities centered around issues that are relevant to the students' community. For example, two of our adventures involve the use of statistical data to construct a business plan that enables our Jasper characters to achieve some important goals. We would like our adventures to motivate students to find a worthy goal of their own, construct a plan for achieving the goal and actually carry out the plan. Similarly, we are hopeful that the emphasis on ecology and recycling that is emphasized in one of our Jasper adventures will motivate students to do something about these issues in their own community. Reports from our collaborative school sites suggest that activities such as these are being generated by students and are actually being carried out.

4.3 Multimedia Publishing Software

The Jasper series includes especially designed multimedia publishing software that allows students and teachers to publish their research about various topics (e.g., about principles of flight or about endangered species) in a multi-media format (e.g., CTGV, 1991). One of the advantages of this software is that it provides a very simple-to-learn mechanism for accessing video segments from other discs that are relevant to the author's topic (there are a growing number of videodiscs published by the Smithsonian, Nova, National Geographic, NASA and so forth). The software also makes it very easy to scan in pictures from stills, to record sounds, and to create hypertext that includes links to a variety of relevant concepts. Students and teachers can also export the stacks they create and send them via telecommunications to others around the nation and the world. For teachers, a collection of HyperCard stacks can provide a rich source of materials that they can use to help students learn about various events.

4.4 Tools for Modeling

We are also beginning to develop tools for modeling that students can use in their explorations of various Jasper adventures. Some of the models work like a spreadsheet and let students see the effects of possible changes in the problems to be solved (e.g., a change in a headwind, in the speed of the aircraft, etc.). Other models let students experiment with aspects of sampling and statistics that are relevant to some of the Jasper adventures. As we work with our scientists and biologists this summer, additional types of models will be introduced. In all cases, our goal is to help students see how the construction of models can simplify the task of making predictions and of understanding complex events.

4.5 Anchored Collaboration through Teleconferencing

The rapidly increasing availability of teleconferencing links to schools makes it possible to extend the concept of "anchored collaboration" even further. Imagine that students work on a videodisc-based adventure (Jasper or otherwise) for several weeks and, at the end of this time, know that they will have the opportunity to participate in an interactive teleconference with other schools across the country (currently, such teleconferences are less expensive when students see a downlinked video but respond by phone). The teleconference focuses on the adventure on which the students have been working. Students will have the opportunity to ask relevant questions about the adventure as well as attempt to solve particular analog "challenges" that are posed.

Events such as these provide the opportunity for a number of benefits. Students can compare their abilities to deal with analog problems to those of other classes, attempt to create presentations that are good enough to appear on the broadcast, set up joint research projects with classes from different areas of the country (e.g., to estimate the number of eagles in their states and compare state laws about endangered species). Overall, these anchored events have the potential to increase students' motivation to learn (because they represent exciting "happenings" for which students prepare). Furthermore, they provide forums for helping students continually expand their horizons and set new standards for themselves.

Teleconferencing and other forms of communication networks also address a dilemma alluded to earlier. It is unrealistic to expect individual teachers to be able to provide the kinds of instruction that leads to a deep understanding of the multitude of concepts and principles that emerge in the context of exploring a video anchor. With teleconferencing, expert scientists can be brought into the classroom and can enhance the learning of teachers as well as students. Text descriptions of the experts' ideas can be made available through electronic means. So can multimedia stacks that include animations and other forms of presentation that help clarify the information to be learned.

The theoretical perspective that underlies our work suggests that a key to the success of the kinds of telecommunication-based broadcasts that we have in mind is the fact that everyone involved has had a chance to explore a particular adventure prior to the broadcast. As noted previously, new ideas are more fully appreciated when people first have the opportunity to explore an environment on their own and are then able to experience the changes in their own noticing and understanding that accompany the introduction of new ideas and perspectives. Under these conditions, they are much more receptive and much more likely to learn (e.g., Bransford, Franks, Vye & Sherwood, 1989; Bransford, Vye, Kinzer & Risko, 1990).

5.0 Summary and Conclusions

We have tried to make and provide support for the following arguments.

1. The idea of integrating science and math instruction should be viewed not as an end in itself but as a means for achieving other goals. The goals that we want to achieve are to help students realize the excitement and importance of mathematical and scientific inquiry, to realize that it is within their potential to engage in such inquiry, and to offer them the kinds of experiences that will set the stage for lifelong learning.

2. Given the goals outlined above, there are a number of reasons for attempting to integrate instruction across traditional disciplinary boundaries. These include the fact that (a) instructional time is limited and could be used much more efficiently, (b) integration across content domains can help students acquire knowledge that is less likely to remain inert, (c) the idea of constructing models and exploring their implications is a fundamental idea that is common to mathematical and scientific inquiry and has powerful implications for lifelong learning.

3. Despite the advantages of (2) above, there are barriers to attempts to integrate instruction across disciplinary boundaries. The most notable one is that it places an extremely heavy burden on teachers. This problem is exacerbated by the extremely limited amount of planning time that is available to most teachers -- especially planning time that involves the opportunity to interact with other colleagues.

4. There are ways to get around the barriers described in (3). One approach involves the use of videodisc-based anchors to create environments that can be explored and discussed collaboratively. Our *Jasper Woodbury Problem Solving* series provides an example of this approach to instruction.

5. The approach to instruction that we described is definitely not limited to Jasper. Through the development of new anchors and the use of telecommunications and teleconferencing, it should become possible to have a positive impact on cross-curricular inquiry on a wide scale.

Endnotes:

1. Preparation of this paper was supported, in part, by grants from the James S. McDonnell Foundation and the National Science Foundation. The ideas expressed herein do not necessarily reflect their views.

2. Members of the Cognition and Technology Group who contributed to this paper are: Linda Barron, John Bransford, Olin Campbell, Dave Edyburn, Ben Ferron, Laura Goin, Elizabeth Goldman, Susan Goldman, Ted Hasselbring, Allison Heath, Charles Kinzer, James Pellegrino, Kirsten Rewey, Vicki Risko, Diana Sharp, Bob Sherwood, Nancy Vye, Susan Warren, and Susan Williams.

3. The *Scientists-in-Action Series* is based on the assumption that students need to see, experience and participate in the activities of real science. One of the ways to help students learn to engage in such scientific inquiry would be to have them work with actual scientists as they work on real issues. Most graduate training is based on apprenticeships. Similarly, innovative teachers have linked students with professional scientists through the use of telecommunications and other media (e.g., Brand, 1989; Curlitz, 1989; Kurshan, 1990). These types of opportunities are excellent for students, but it also seems clear that it can be very difficult to provide sustained opportunities for apprenticeship experience for all students enrolled in college, high school or middle school; there are usually too many students and too few scientists. Our plan is to use video technology to simulate a series of opportunities to work with professional scientists on a variety of issues. We do not want to replace the opportunity for actual apprenticeships; we want to supplement them so that apprenticeship-like experiences can be more frequent for all.

Each episode in our proposed series will allow the viewers (students) to sit in on working meetings involving multi-disciplinary teams of scientists who are attempting to solve important problems. The episodes will involve problems that are real rather than imaginary and/or over simplified. This means that we will need to work closely with experts in the areas relevant to each episode. For the pilot episode that we have developed, our team of experts included A.B. Bond (Professor of Engineering), David Wilson (Professor of Chemistry and Engineering), and Hubert Dixon, Kaday Gray, Robert Maglievaz and staff, members of the Vanderbilt Student Environmental Health Project. All of these individuals have been directly involved in the kinds of issues that our pilot video portrays. We are also fortunate to be working with Beth Leopold, who has an extensive background in video production and health-science issues.

Like the Jasper series discussed earlier, the *Scientists-in-Action Series* is designed to invite thinking rather than simply present facts in a documentary fashion. The viewers participate in the problem solving and later get to compare their ideas with the other experts. All participants (the students as well as the scientists) have access to written materials about existing theories and data that allow them to take systematic approaches to hypothesis formation and testing rather than simply be restricted to a trial and error approach to problem solving. The major emphasis is on helping students learn to use theory, data and experimental procedures to generate and evaluate theories and make arguments about the plausibility or feasibility of specific view points.

4. We thank Joe B. Wyatt, Chancellor of Vanderbilt University, for his leadership and support in helping us develop the Jasper series, finding school-based sites in 9 states, and making possible the kinds of collaborative ventures (e.g., making science-based hypercard stacks) that provide deeper understandings of events in the Jasper series.

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Integrating Mathematics and Science

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The call for integrating mathematics and science is a constant theme in both mathematics and science education. It is a logical and compelling idea since so much mathematics is developed in response to scientific questions, and since science is completely dependent on mathematics throughout. It seems obvious that each subject would be enriched by the other, that learning would be greater and deeper in an environment that mixed mathematics and science. The arguments for this integration are so compelling it is a wonder that the two are not completely integrated as a matter of course. And yet, true integration is an ideal seldom achieved in practice.

At the elementary and middle grades, the match is usually a force fit because the traditional topics and treatments in mathematics and science are so far apart. An indication of the divorce of mathematics from science is that the kinds of numbers used in science are seldom treated in mathematics at the lower grade levels -- numbers with units attached (6 feet instead of 6) and numbers that include experimental error (6.0 $\pm$ .2 feet). In elementary and middle school science, numbers are strenuously avoided, too often because many elementary educators are uncomfortable thinking with numbers.

In high school and college the problem is the specialization of faculty and courses -- there is little interest or incentive for a mathematics teacher to get involved with science concepts and vice versa. Thus, any attempt to integrate the disciplines usually involves trying to schedule topics so they are taught at the same time or in a meaningful sequence between a mathematics and science course. There are many problems with this approach: it is usually up to the student to do the integrating; the scheduling demands disrupt the order within each course; and the integration, if achieved one year, tends to dissolve in successive years.

The solution to these difficulties must start with an acknowledgement of the seriousness of the educational problems that integration is invoked to correct. The desire to integrate the two disciplines must come from, and be part of, a desire to re-fashion mathematics and science instruction in light of our persistent and catastrophic failure to prepare students for the future. Any solution to these failures will have to involve new approaches to teaching and the will to overcome minor scheduling difficulties.

At TERC we have been evolving a radical approach to mathematics and science teaching which addresses these deeper issues while at the same time achieves a degree of integration. This integration is an interesting consequence of essential changes in the learning environment that involve moving away from teaching students and toward setting up rich learning situations. As Seymour Papert is fond of saying, "Better learning will not come from finding better ways for the teacher to instruct but from giving the learner better opportunities to construct."

Our approach is to empower students to undertake original investigations, to do mathematics and science. By focusing on the goal of thoughtful student participation in original work, we tap mathematics and science for inspiration, a strategy which we hope brings to education the excitement of discovery that motivates students to become engaged. This strategy also emphasizes the importance of the learner in constructing understanding that comes from a self-motivated need to know.

Of course, like most ideas in education, this is hardly new. At the beginning of the century Dewey called for education based on "continual reorganization, reconstruction and transformation of [student] experience." Twenty-eight years ago, Philip Morrison in an article titled "Less May Be More" said, "... I am speaking for ... a laboratory involvement that may be painfully slow, that 'doesn't get anywhere.' You don't 'cover the material,' but you spend a good many hours of the week doing something."

When student projects are tried in schools, too often they result in activity without learning, motion leading nowhere. Of course, students have to be thoughtfully engaged. As Morrison continues, "That's what I'd like to see ... the free use of simple materials, ... [with] analysis." Dewey in 1938 said, "But observation alone is not enough. We have to understand the significance of what we see, hear, and touch .... The crucial educational problem is that of procuring the postponement of immediate action upon desire until observation and judgment have intervened."

By emphasizing thoughtful original student investigations -- projects -- we do not intend that mathematics and science education should be composed of nothing else. Were students doing nothing but projects and not gaining any systematic understanding of the fields, we would probably come out strongly for some "book learning." However, student project activities are all but absent from mathematics and science education, and with that absence there is a lack of reality to mathematics and science education, a lack of connection to problems of concern to students, and, necessarily, a lack of interest, solid learning, and desire to learn more.

A school that makes a real commitment to student project activities must re-think the entire mathematics and science curriculum both to create time for a healthy injection of project activities and to reorient the remainder of the curriculum to support project work. Both changes are healthy but difficult. The former change requires new and interesting project activities that do support "observation and judgment." The latter change requires schools to determine how the remainder of the curriculum should be altered to prepare students for progressively more sophisticated and independent project activities that become closer and closer approximations to what mathematicians and scientists do. And of course, these changes force schools to come to grips with new approaches to evaluation appropriate in a project-oriented learning environment.

Much of our work at TERC is oriented to three areas -- innovative student project activities, better curricula to support a project environment, and alternative assessment. What is particularly interesting in the context of this discussion is the extent to which these areas integrate mathematics and science. The *Used Numbers* project, for instance, provides a strand in the elementary curriculum that bridges math and science by covering the mathematics of measurement and statistics.

In exploring the ways that technology can help support project-oriented science, we found that telecommunications, microcomputer-based labs, and analytical tools were particularly attractive options. Telecommunications and microcomputers can give students the tools they need individually and in groups to begin to experience investigations that are original and important. Telecommunications provides unique opportunities for students to collaborate and share ideas, techniques, and data, an approach we call *Network Science*. Inexpensive microcomputers can be versatile instruments giving students the functionality of racks of electronics that not long ago were reserved for advanced research. With these microcomputer-based lab (MBL) interfaces, students become better experimenters and able to explore first hand a broad range of phenomena on which science is based. These same microcomputers can be used for computations and data analysis, allowing students to be theorists, and to move between theory-building and experimenting with ease. In such situations, there is no distinction between mathematics and science.

It is a common misconception that only gifted or strongly motivated students can learn through project activities. TERC staffers Beth Warren, Ann Rosebery, and Faith Conant have shown that project activities are also effective with language minority students in "basic skills" programs who test several grades below level. In other TERC field tests, computer-based, project-oriented materials have been shown to be extremely effective for students with mild learning and behavior disorders. The TERC *Star Schools* project registered important success among students who were otherwise performing poorly; cooperation, interest in science, leadership, and performance improved for all students.

What we are saying, then, is that projects, when they encourage thoughtful student exploration, neatly integrate mathematics and science. This is not too surprising, since many projects are based on interesting situations which require a quantitative understanding of cause and effect, that is, they require a mathematical treatment of science topics.

Appendix A

Author Biographies

Carl F. Berger is Director of Instructional Technology and Professor of Science Education at the University of Michigan. In the Office of the Vice President for Information Technology, he has responsibility for the Office of Instructional Technology, The Instructional Technology Laboratory, Campus distance learning, and multimedia on the three campuses of the University.

He has been a professor of Science Education since 1972 and was Associate Dean and Dean of the School of Education from 1979 to 1988. Carl Berger started his technological career as a teacher in the Grant Joint Union School District, North Sacramento, California. While there for eight years, he taught science and math in junior high and high school. He left school teaching to become staff physicist for the *Science Curriculum Improvement Project (SCIS)* at the University of California, Berkeley where he received his doctorate in 1971. From 1974 through 1984, he was an author for Science, the Houghton Mifflin elementary science series.

He has been director of six NSF Science Institutes and has designed several computer programs integrating science and mathematics and statistics. With David Jackson of the University of Georgia and Billie Edwards of Renaissance High School, Detroit, he received the 1990 NARST Award for Practical Applications of Science Education Research for their research entitled "Teaching the Design and Interpretation of Graphs through Computer-Aided Graphical Data Analysis."

As Director of Instructional Technology, he oversees the development of more than 50 instructional projects, ranging from applications of *MAPLE* and *Mathematica* to the use of Microcomputer-Based Laboratories in Teacher Education. His current research interests include the measurement of student learning through the use of log files and conceptual maps.

Donna F. Berlin is an Associate Professor in the Department of Educational Theory and Practice at The Ohio State University. She teaches undergraduate, graduate, and professional (in-service) courses related to elementary and middle school mathematics, the use of technology (e.g., computers, calculators) in the classroom, instructional methods and media, and child development and learning theory. Berlin earned her B.S. from Syracuse University, M.A. from New York University, and Ph.D. from The Ohio State University majoring in early and middle childhood education with a specialization in mathematics education.

Berlin's areas of expertise include the integration of science and mathematics education, elementary and middle school mathematics education, and the integration of technology into the curriculum. She has published many theoretical, research, and curriculum manuscripts and presented numerous papers at state, national, and international conferences, seminars, and workshops related to her areas of expertise. Berlin has served as the chair of the School Science and Mathematics Association Task Force for the Integration of Science and Mathematics Education; Editor of the SSMILES (School Science and Mathematics Integrated Lessons) Department in the journal School Science and Mathematics; and Co-Director of the project "A Network for Integrated Science and Mathematics Teaching and Learning" funded by the National Science Foundation, School Science and Mathematics Association, and The Johnson Foundation.

She has also been a member of the Executive Board and the Board of Directors of the School Science and Mathematics Association and the Editorial Board for the Journal of Research in Science Teaching.

Currently, Berlin serves as the research coordinator of the focus area "Integration Across Content" for The National Center for Science Teaching and Learning and as the Mathematics Education Associate for the Eisenhower National Clearinghouse for Mathematics and Science Education. Both the center and the clearinghouse are funded by the Office of Educational Research and Improvement of the U.S. Department of Education.

John D. Bransford is Centennial Professor of Psychology and Co-Director of the Learning Technology Center at George Peabody College, Vanderbilt University. He is known for work on thinking and learning. Most recently, he and his colleagues have focused on the design of environments that make learning meaningful and help students integrate knowledge from different subject areas (e.g., mathematics, science, history and literature). Bransford and his colleagues' research highlights uses of technology that encourage generative learning rather than the passive reception of knowledge. The research involves technology applications that are simple, yet powerful, and address implementation into existing curricula.

After receiving his Ph.D. in cognitive psychology from the University of Minnesota, Bransford joined the faculty at the State University at New York at Stony Brook. He moved to Vanderbilt as a professor of psychology and later became a professor of Teaching and Learning at Peabody College. He is currently the Senior Research Scientist in the John F. Kennedy Center.

Bransford serves as consulting editor on several publications (e.g., Cognition and Instruction, Human Learning, Discourse Processes, Technology and Learning). He has published extensively in the fields of psychology and education.

John A. Dossey is the Distinguished University Professor of Mathematics at Illinois State University. He received his B.S. and M.S. degrees in mathematics from Illinois State University. Following teaching junior and senior high school mathematics, he completed his Ph.D. in mathematics education at the University of Illinois at Urbana-Champaign. He has taught summer sessions at Lewis and Clark College, University of Northern Iowa, and Indiana University. During the 1993-94 academic year, he was the Visiting Professor of Mathematical Sciences at the U.S. Military Academy at West Point, NY.

During 1986-88, Dossey served as President of the National Council of Teachers of Mathematics, leading the organization through the formulation of a set of national standards for school mathematics. He has also served on the Board of Governors of the Mathematical Association of America, the Mathematical Sciences Education Board at the National Research Council, the Conference Board of the Mathematical Sciences, and served as chair of the Mathematical Sciences Advisory Committee of the College Board.

He has authored or co-authored over 35 books and 75 articles/monographs ranging from secondary school textbooks to research work in assessment to materials on international comparisons in school mathematics. His most recent work has dealt with large scale assessment studies and analyses of the National Assessment of Educational Progress results at the national and state-by-state levels.

Lynn A. Steen is Executive Director of the Mathematical Sciences Education Board, on leave from his position as Professor of Mathematics at St. Olaf College in Northfield, Minnesota. After graduating in 1961 from Luther College in Decorah, Iowa, he undertook graduate studies at the Massachusetts Institute of Technology, from where he received a Ph.D. in mathematics in 1965. He has been a member of the St. Olaf faculty since 1965.

Steen is the author of fourteen books, including the report on mathematics education Everybody Counts from the National Research Council, the report Calculus for a New Century, and the earlier survey Mathematics Today. His most recent book, On the Shoulders of Giants: New Approaches to Numeracy, represents a major initiative of the National Academy of Sciences to stimulate fundamental change in school mathematics.

Steen has written numerous articles about mathematics, computer science, and mathematics education for periodicals such as Educational Leadership, Scientific American, Science News, and Science. His article on "Numeracy" was included in a recent special issue of Daedalus on "Literacy in America."

Steen has served as Co-Director of the Minnesota Mathematics Mobilization, Telegraphic Reviews Editor for the American Mathematical Monthly, and chair of the MAA Committee on the Undergraduate Program in Mathematics (CUPM). In previous years, he has served as President of the Mathematical Association of America, Secretary of Section A (Mathematics) of the American Association for the Advancement of Science, Chair of the Council of Scientific Society Presidents, Chair of the Conference Board of the Mathematical Sciences, and as a member of the Advisory Committee for the Mathematical Sciences of the National Science Foundation.

Robert F. Tinker is the Chief Science Officer at TERC in Cambridge, MA a non-profit educational research and development group that specializes in innovations in mathematics and science. He developed a life-long commitment to improved mathematics and science education in the civil rights movement, teaching physics and mathematics at Stillman College, an historically black college in Alabama.

In the late 60s, Tinker earned his Ph.D. in experimental low temperature physics from MIT and was deeply involved with physics education reform of that period. At Amherst College, he taught electronics for scientists as the first integrated analog and then digital circuits were marketed. This led to the idea of using computers in the teaching lab and, eventually, to the creation of the microcomputer-based lab idea.

At TERC during the last 17 years, Tinker has fostered the development of many innovations, including the initial work in microcomputer-based labs and network science. The workshops he led in the 1980s started many educators using computers. The *Kids Network* which he envisioned in 1984 now gives a quarter-million children annually authentic science experiences. He has helped design several award-winning software packages and continues to program and design software.

His current interests include building international networks that combine publishable science with educational reform, educational networking policy, and the applications of a range of technologies to education. He is the principle investigator in several related projects and writes and speaks widely on the future of mathematics, science, and technical education.

Appendix B

Wingspread Conference Program

A Network for Integrated Science and Mathematics Teaching and Learning

Friday, April 26, 1991

11:45 a.m.	Hospitality	Wingspread
12:00 noon	Luncheon	
1:00 p.m.	<u>Welcome to Wingspread</u> **Susan J. Poulsen** Associate Program Officer The Johnson Foundation	The House
	<u>Opening Remarks</u> **Donna F. Berlin** Integration Network Co-Director The Ohio State University at Newark Newark, Ohio	
	<u>Plenary Session</u> The Integration of Science and Mathematics Teaching and Learning	
	<u>Panel</u> Mathematician's and Scientist's Perspectives	
	Lynn A. Steen Mathematician St. Olaf College Northfield, Minnesota	
	John G. King Physicist Massachusetts Institute of Technology Cambridge, Massachusetts	
	<u>Discussion</u>	
2:30 p.m	Refreshments	

3:00 p.m.	Plenary Session Continues Panel Mathematics Teacher Educator's and Science Teacher Educator's Perspectives **John A. Dossey** Mathematics Teacher Educator Illinois State University Normal, Illinois **Carl F. Berger** Science Teacher Educator University of Michigan Ann Arbor, Michigan Discussion	
4:15 p.m.	Small Groups (8): Discussion	
5:30 p.m.	Leisure	
6:00 p.m.	Hospitality	Wingspread
6:30 p.m.	Dinner	
7:30 p.m.	Plenary Session The Integration of Science and Mathematics Teaching and Learning Panel Cognitive Scientist's and Educational Technologist's Perspectives Introductions **Darrel W. Fyffe** Executive Secretary School Science and Mathematics Association Bowling Green State University Bowling Green, Ohio	The House

John D. Bransford
Cognitive Scientist
Vanderbilt University
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Robert F. Tinker
Educational Technologist
TERC
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<u>Discussion</u>

8:45 p.m.	Adjournment	

Saturday, April 27, 1991

9:00 a.m.	Small Groups (4)	Wingspread
	Task: Define and develop a rationale for the integrated teaching and learning of science and mathematics.	
10:15 a.m.	Coffee and tea	Wingspread
10:45 a.m.	Small Groups (4)	Wingspread
	Task: List guidelines for the infusion of integrated teaching and learning of science and mathematics into school practices.	
12:00 noon	Hospitality	Wingspread
12:15 p.m.	Luncheon	
1:45 p.m.	<u>Plenary Session</u>	The House
	Group Reports and Discussion Chair: **Donna F. Berlin**	
3:00 p.m.	Refreshments	The House

3:30 p.m.	Small Groups (4) **Task: Identify a list of high priority research questions relevant to the integrated teaching and learning of science and mathematics.**	Wingspread
4:45 p.m.	<u>Plenary Session</u> Group Reports and Discussion Chair: **Arthur L. White** Integration Network Co-Director The Ohio State University Columbus, Ohio	The House
6:00 p.m.	Hospitality	Wingspread
6:30 p.m.	Dinner	
7:30 p.m.	Adjournment	

Sunday, April 28, 1991

9:00 a.m.	<u>Plenary Session</u> The Integration of Science and Mathematics Teaching and Learning: Observations and Reactions Chair: **Arthur L. White** **David Bodnar** Elementary School Teacher Washington Elementary School Pittsburgh, Pennsylvania	The House

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10:30 a.m.	Coffee and tea	
11:00 a.m.	Plenary Session Continues	
	Group Discussion and Synthesis	
	Co-Chairs:	
	Arthur L. White	
	Donna F. Berlin	
	Darrel W. Fyffe	
12:00 noon	Hospitality	Wingspread
12:15 p.m.	Luncheon	
1:30 p.m.	Adjournment	

Appendix C

Wingspread Conference Participants

A Network for Integrated Science and Mathematics Teaching and Learning

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Appendix D

Report from the NSF/SSMA Wingspread Conference: A Network for Integrated Science and Mathematics Teaching and Learning

Report from the NSF/SSMA Wingspread Conference: A Network for Integrated Science and Mathematics Teaching and Learning

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President Bush (1990) has set as one of America's educational goals for the year 2000, "U.S. students will be first in the world in science and mathematics achievement." (p.19) Integration is repeatedly referred to in mathematics and science education reform as a necessary component for science and mathematics education (e.g., the American Association for the Advancement of Science [AAAS] Project 2061, [1989]; The National Science Teachers Association [NSTA] Scope, Sequence, and Coordination, (personal communication, January 25, 1991); and The National Council of Teachers of Mathematics [NCTM] Curriculum and Evaluation Standards for School Mathematics, [1989]). Consider the following examples from recent documents on science and mathematics education reform. They are indicative of the current emphasis on the concept of integration.

> *The alliance between science and mathematics has a long history, dating back centuries. Science provides mathematics with interesting problems to investigate, and mathematics provides science with powerful tools to use in analyzing data .... Science and mathematics are both trying to discover general patterns and relationships, and in this sense they are part of the same endeavor. (Rutherford & Ahlgren, 1990, pp.16-17)*

> *Since mathematics is both the language of science and a science of patterns, the special links between mathematics and science are far more than just those between theory and applications. The methodology of mathematical inquiry shares with the scientific method a focus on exploration, investigation, conjecture, evidence, and reasoning. Firmer school ties between science and mathematics should especially help students' grasp of both fields. (National Research Council, 1990, pp. 44-45)*

The Wingspread Conference

In an effort to explore ways to improve science and mathematics education in elementary, middle, and high schools through integrated teaching and learning of these two disciplines, the School Science and Mathematics Association (SSMA), The National Science Foundation (NSF), and The Johnson Foundation sponsored a conference including educators, professional association leaders, curriculum developers, and members of the scientific community including scientists, mathematicians, and technologists. The conference took place at The Johnson Foundation Wingspread Conference Center in April of 1991. The purpose of the conference was to gain a better understanding of integrated science and mathematics teaching and learning by focusing on three critical elements: (a) development of definition(s) of integration and a rationale for integrated teaching and learning of science and mathematics, (b) specification of guidelines for infusion of integrated teaching and learning of science and mathematics into school practice, and (c) identification of high priority research questions related to integrated teaching and learning of science and mathematics.

At the opening session, Dr. Donna Berlin of The Ohio State University at Newark presented a review of the literature on integration of science and mathematics education. Her overview of the theoretical, research, curriculum, and instructional literature in the field of integration revealed that of 423 citations, approximately 77% were essentially science instructional activities which included mathematics-related concepts. These mathematics concepts were rarely stated as objectives in the activities. This type of integration is a product of the nature of the activity rather than of conscious design and involves isolated activities rather than organized programs.

Berlin's review highlighted a profound lack of research documents. Out of 423 citations, only 99 (23%) related to theory and research. Of these 99 citations, 77 concerned theory and 22 concerned research. Furthermore, some of these 22 were only tangentially related to the integration of science and mathematics. To compound the problem, inconsistent definitions of integration precluded valid comparisons within the research literature. Research was often incomplete; researchers examined the effect of integration on science or mathematics outcomes, but not both. There is clearly a need for careful conceptualization and additional research on integrated science and mathematics teaching and learning.

The Question of Definition

The definitions of integration suggested by the conference participants varied. Although a consensus was not reached, several key components did emerge. Conference participants discussed the need to attend to integrated content (what is taught) and integrative teaching methods (how it is taught) and concluded that these needs may be quite distinct. One working group proposed the following definition: "Integration infuses mathematical methods in science and scientific methods into mathematics such that it becomes indistinguishable as to whether it is mathematics or science." Another group suggested that integration is the process of blending the quantifying aspects of mathematics and the contextual aspects of science. Some participants cautioned against the merging of the two disciplines for fear of losing the important philosophical, methodological, and historical differences between the two.

It is not clear to what extent mathematics and science should be integrated. The key question is clearly this: Which concepts and/or processes of mathematics and science are naturally related and which should remain discipline specific?

Other points of notable agreement surfaced during the discussion. Many of the participants championed a project approach to connect science, mathematics, and events outside the classroom. Proponents of the project approach cited efficient use of time and ability to make knowledge relevant (less inert) as its major advantages. As described by John Bransford of the Learning Technology Center at Vanderbilt University, projects are "...helping students understand the value of the knowledge that they are learning and its connections with other aspects of their knowledge." Conference participants clearly valued a constructivist perspective. According to Lynn Steen of St. Olaf College, "Children learn by doing, their actions help construct their personal knowledge. Involvement in learning increases as does long term retention."

The Challenge of Infusion

Conference participants were generally in accord on the integrated teaching of science and mathematics; there was, however, less agreement on the integration of content and processes. Although integration eluded definition, conferees arrived at a rationale for its infusion into school practice. The potential benefits cited included:

1. Helping students realize that mathematics and science are everywhere.
2. Providing opportunities for out of school resource persons to become involved.
3. Stimulating group interaction and social development.
4. Bridging understanding between concrete and abstract representations.
5. Developing quantitative and causal appreciation of reality with emphasis on information use rather than acquisition.
6. Providing opportunities to put ideas together and deepen understanding.
7. Encouraging relevant, exciting science and mathematics in schools.

John Bransford summed up his view of integration as follows: "[It is] highly desirable not as an end in itself, but as a means to achieve other goals. The goals that we want to achieve are to help students experience the excitement and importance of mathematical and scientific inquiry, to realize that it is within their potential to engage in such inquiry, and to offer them the kinds of experiences that will set the stage for lifelong learning."

The debate concerning the infusion of integrated science and mathematics into classroom practice raised a number of issues including: resources and methodologies, integrative curricula, teacher preparation, outcome assessment, and implementation strategies. The conferees agreed that teacher preparation is a major hurdle to integrating science and mathematics into school practice. Teacher-related obstacles include teacher knowledge, experience, attitudes, and beliefs. In order to optimize meaningful linkage between science and mathematics, it must be determined what teachers need to know about a number of issues, including:

1. The nature of science and mathematics.
2. Concepts and principles of science and mathematics.

3. Interrelationships of processes and skills of science and mathematics.
4. Curriculum, instruction, and learning theories.
5. Selection and sequencing of learning activities.
6. Organization and management of the learning environment.
7. Comprehensive assessment practices.

There are other issues and influences which can be described as external to the classroom including school structure, organization, and administration; social and cultural influences; public perceptions and incentives; and economic and political forces. The traditional boundaries between content areas, scheduling practices, criteria for resource allocation, assessment practices (format and focus), collaboration incentives, and public perceptions need to be described and understood.

Several participants proposed technology-based solutions to the infusion issue. Carl Berger of the University of Michigan suggested that "technology can blast through the barrier between science and mathematics .... This technology will cause us to rethink our pedagogy." John Bransford recommended the use of videodisc-based anchors to create environments that can be explored and discussed in a collaborative manner. The use of these and other types of electronic communications may provide avenues for cross discipline, inquiry-based learning.

The Next Step

John Dossey of Illinois State University summed up the difficulties of translating ideas into action. "Integrated mathematics and science programs for school curricula have strong support at the discussion level. However, ... significant challenges must be addressed. The degree to which a carefully constructed program for the development of sample integrated programs, research agenda to document their efficiency, production of materials to support teachers, programs of professional development for teachers, and plans for developing public support are developed, implemented, and monitored will, in the end, determine the probability of the existence of integrated programs of mathematics and science education in American schools."

Follow-up activities to this conference will be facilitated by a network of interested and concerned professionals. The network includes electronic mail communications such as SMILENET (the Science and Mathematics Integrated Learning Environment Network); newsletter articles with broad dissemination such as those published by the National Association for Research in Science Teaching (NARST), National Council of Teachers of Mathematics (NCTM), National Science Teachers Association (NSTA), and SSMA; special publications such as research reports, monographs, collections of learning activities, bibliographies, and resource lists; workshop, symposia, and paper presentations (e.g., AAAS, NARST, NCTM, NSTA, SSMA); and a collaborative task force on the integration of science and mathematics education involving NARST, NCTM, NSTA, and SSMA.

The National Center for Science Teaching and Learning (NCSTL) conducts, coordinates, and facilitates research on the integration of science with other content areas. Donna Berlin, coordinator of NCSTL's research on integration, and Arthur White, Center Director, are committed to sustaining research, development, communication, and dissemination efforts related to the integrated teaching and learning of science and mathematics.

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